agriculture, forestry & fisheries

Department: Agriculture, Forestry and Fisheries
REPUBLIC OF SOUTH AFRICA

ALGOA BAY SEA-BASED AQUACULTURE DEVELOPMENT ZONE

DISPERSION MODELLING REPORT FOR ALGOA 1 & 7

March 2019

ANCHOR research & monitoring

Anchor Research and Monitoring Report No. 1817/2

ALGOA BAY
SEA-BASED AQUACULTURE DEVELOPMENT ZONE

DISPERSION MODELLING REPORT ALGOA 1 & 7

March 2019

Report Prepared for:
Department of Agriculture, Forestry & Fisheries

Report Prepared by:
Anchor Research and Monitoring (Pty) Ltd.
8 Steenberg House, Silverwood Close, Tokai 7945, South Africa
https://anchorenvironmental.co.za

Authors: Amy Wright, Ken Hutchings, Jessica Dawson and Barry Clark

Title Page Photo Credit: Shutterstock

PROJECT DETAILS

Objective	Conduct dispersion modelling to inform feasibility of precincts Algoa 1 and 7 for finfish aquaculture in support of an application for Environmental Authorisation for an Aquaculture Development Zone in Algoa Bay in terms of the National Environmental Management Act, 1998 (Act No 107 of 1998) – Basic Assessment Process
Anchor Project Name	Algoa Bay ADZ Basic Assessment Process Benthic Mapping and Dispersion modelling
Anchor Project Number	1817
Deliverable	2

Citation: Wright AG, Hutchings K, Dawson J, & Clark B. 2019. Algoa Bay Sea-based Aquaculture Development Zone. Dispersion Modelling Study for Algoa 1 and Algoa 7 – February 2019. Report No. 1817/2. Report prepared for the Department of Agriculture, Forestry and Fisheries (DAFF) by Anchor Research and Monitoring. 41 pp. March 2019

DETAILS OF THE BASIC ASSESSMENT PROCESS

Applicant	Department of Agriculture, Forestry & Fisheries
Purpose of application	Aquaculture Development Zone in Algoa Bay
Environmental Assessment Practitioner (EAP)	Vera Massie and Dr Barry Clark from Anchor Research & Monitoring (Pty) Ltd
Anchor Project Name	Algoa Bay Aquaculture Development Zone Basic Assessment Process
Anchor Project Number	1808
Status	Pre-application
Application submission date	Not submitted
Competent Authority Reference	Not currently assigned
Case Officer	Not currently assigned

OVERVIEW OF PROJECT OUTPUTS
BASIC ASSESSMENT REPORT AND APPENDICES

Basic Assessment Report (BAR)	**Pre-Application BAR**, Draft BAR, Final BAR
Appendix A	Details of EAP, Expertise and Declaration
Appendix B	Details of Specialists, Expertise and Declaration
Appendix C	Background Information Document
Appendix D	Specialist studies: 1. Benthic Mapping Assessment for the Proposed Algoa Bay Sea-Based Aquaculture Development Zone (Dawson *et al.* 2019) **2. Dispersion Modelling Study for the Proposed Algoa Bay Sea-Based Aquaculture Development Zone (Wright *et al.* 2019)** 3. Marine Specialist Study 2019 (Hutchings *et al.* 2019) 4. Maritime Underwater Heritage Specialist Study (Gribble 2019) 5. Comparative Assessments for the Development of the Proposed Sea Based Aquaculture Development Zone Located within Algoa Bay in the Eastern Cape in South Africa (Rhodes University August 2016) a. Socio-economic Report b. Ecological Report c. Feasibility study
Appendix E	Stakeholder Consultation Report
Appendix F	Environmental Management Programme (EMPr)
Appendix G	Additional Information

TABLE OF CONTENTS

GLOSSARY

Alien species	Species that become established in areas outside their natural, native range.
Amphipod/a	Crustaceans with no carapace and a laterally compressed body
Anaerobic bacteria	Unicellular organisms that do not require oxygen to function
Annelid/a	Segmented worms including earthworms, leeches, and a large number of mostly marine worms known as polychaetes.
Anthropogenic	Environmental pollution originating from human activity
Arthropod/a	An arthropod is an invertebrate animal with an exoskeleton, a segmented body and jointed appendages. Arthropods form the phylum Arthropoda, which includes crustaceans.
Ascidian	Primitive chordates resembling sac-like marine filter feeders, also known as sea squirts.
Avifauna	The birdlife of a particular region or habitat.
Baseline	Information gathered at the beginning of a study which describes the environment prior to development of a project and against which predicted changes (impacts) are measured.
Benthic	Pertaining to the environment inhabited by organisms living on or in the ocean bottom
Biodiversity	The variety of plant and animal life in a particular habitat.
Biological monitoring survey	A scientific study of organisms to assess the condition of an ecological resource, involving the collection and analysis of animal and/or plant samples which serve as indicators to the health/recovery of an affected system.
Biota	Living organisms within a habitat or region
Biomass	The mass of living biological organisms in a given area or ecosystem.
Bioregion	A region defined by characteristics of the natural environment rather than by man-made divisions.
Chart datum	Chart Datum is level on the shore corresponding with the Lowest Astronomical Tide (LAT) as from 1 January 2003.
Copepod	A group of small crustaceans found in the sea and nearly every freshwater habitat. Some species are planktonic (drifting in the water column), while some are benthic (living on the ocean floor).
Construction phase	The stage of project development comprising site preparation as well as all construction activities associated with the development.
Crinoid	Feather stars belong to the phylum Echinodermata. As juveniles, they are attached to the sea bottom by a stalk with root-like branches. In the adult stage, they break away from the stalk and move about freely.
Coralline	Corallines are red algae in the order Corallinales. They are characterized by a thallus that is hardened by calcareous deposits contained within the cell walls.
Crustacea/n	Generally differ from other arthropods in having two pairs of appendages (antennules and antennae) in front of the mouth and paired appendages near the mouth that function as jaws.
Cumulative impacts	Direct and indirect impacts that act together with current or future potential impacts of other activities or proposed activities in the area/region that affect the same resources and/or receptors.
Diatom	A major group of algae that makes up the most common type of phytoplankton. Most are unicellular but they can group together to form colonies.
Dinoflagellate	A large and diverse group of unicellular protists, most of which are marine, and that can either be free-living in the plankton, or benthic.
Dissipative beach	Waves break further offshore and lose energy (dissipate) across the wide surf zone. At a dissipative beach high waves and a wide surf zone restrict most bathers to the inner swash zone.
Echinoderm/ata	Marine invertebrates with fivefold radial symmetry, a calcareous skeleton and tube

	feet (e.g. starfishes, sea urchins, sea cucumbers)
Echiuroids	Spoon worms
Elasmobranchs	Sharks, skates and rays
Encrusting algae	A type of coralline algae that grows in low carpets on rocky shores.
Endemicity /endemism	A species unique to a defined geographic location. Organisms that are indigenous to an area are not endemic if they are found elsewhere.
Environment	The external circumstances, conditions and objects that affect the existence of an individual, organism or group. These circumstances include biophysical, social, economic, historical and cultural aspects.
Environmental Authorisation	Permission granted by the competent authority for the applicant to undertake listed activities in terms of the NEMA EIA Regulations, 2014.
Environmental Impact Assessment	A process of evaluating the environmental and socio-economic consequences of a proposed course of action or project.
Environmental Management Programme	A description of the means (the environmental specification) to achieve environmental objectives and targets during all stages of a specific proposed activity.
Epibiotic	An organism that lives on the surface of another living organism without causing harm to its host.
Epiphyte	An organism that grows on the surface of a plant.
Far field	The region of the receiving water where buoyant spreading motions and passive diffusion control the trajectory and dilution of the effluent discharge plume.
Faunal community	A naturally occurring group of native animals that interact in a unique habitat.
Gastropod/a	Molluscs (e.g. snails and slugs)
Groyne	A low wall or sturdy timber barrier built out into the sea from a beach to reduce erosion and drifting.
High shore	The section of the intertidal zone reaching from the extreme high water spring tide to the mean high water neap tide.
Ichthyoplankton	The eggs and larvae of fish, which are usually found in the sunlit zone of the water column (epipelagic/photic zone).
Impact	A change to the existing environment, either adverse or beneficial, that is directly or indirectly due to the development of the project and its associated activities.
Inert	Unreactive or non-threatening
Intertidal zone	The section of the marine environment that lies exposed at low tide and submerged at high tide.
Infauna	The assemblage of organisms inhabiting the seafloor.
Invasive species	Alien species capable of spreading beyond the initial introduction area and have the potential to cause significant harm to the environment, economy or society.
Invertebrate	An animal without a backbone (e.g. a starfish, crab, or worm)
Longshore current/drift	The movement of material along a coast by waves that approach at an angle to the shore but recede directly away from it.
Low shore	The section of the intertidal zone reaching from the mean low water neap tide to the extreme low water spring tide.
Macrofauna	Animals larger than 0.5 mm.
Macroscopic	Visible to the naked eye.
Marine Protected Area	An area of sea and coastline that is dedicated to the protection of biodiversity and natural and cultural resources and is managed in a structured and legal manner. Different levels of MPAs exist, ranging from complete no-take zones (where nothing may be disturbed, caught or removed) to partial-take MPAs which have a suite of regulations that determine what activities may take place in which zone.
Meiofauna (meiobenthos)	Small benthic invertebrates that are larger than microfauna but smaller than macrofauna.
Microscopic	So small as to be visible only with a microscope.
Microtidal	A term applied to coastal areas in which the tidal range is less than 2 m.
Mitigation measures	Design or management measures that are intended to minimise or enhance an

	impact, depending on the desired effect. These measures are ideally incorporated into a design at an early stage.
Mixing zone	An administrative construct which defines a limited area or volume of the receiving water where the initial dilution of a discharge is allowed to occur, until the water quality standards are met. In practice, it may occur within the near field or farfield of a hydrodynamic mixing process and therefore depends on source, ambient, and regulatory constraints.
Mollusc/a	Invertebrate with a soft unsegmented body and often a shell, secreted by the mantle.
Near field	The region of a receiving water where the initial jet characteristic of momentum flux, buoyancy flux and outfall geometry influence the jet trajectory and mixing of an effluent discharge.
Nearshore	Zone extending seawards of Chart Datum to a point where the seabed is less than 10 m depth at Chart Datum, or the distance offshore from Chart Datum is less than 500 m, whichever is greater.
No-take zone	A type of MPA where no fishing is allowed
Offshore	The area seaward of the nearshore environment boundary.
Operational phase	The stage of the works following the Construction Phase, during which the development will function or be used as anticipated in the Environmental Authorisation.
Ophiurida	An order of echinoderms known as the brittle stars.
Pelagic	Within the water column.
Phytoplankton	Ocean dwelling microalgae that contain chlorophyll and require sunlight in order to live and grow.
Polychaete (Polychaeta)	Segmented worms with many bristles (i.e. bristle worms).
Population fragmentation	A form of population segregation often caused by habitat fragmentation and may lead to a decrease in genetic variability.
Recommended Mixing Zone (RMZ)	An administrative construct which defines a limited area or volume of the receiving water where the initial dilution of a discharge is allowed to occur, until the water quality standards are met. In practice, it may occur within the near field or far field of a hydrodynamic mixing process and therefore depends on source, ambient, and regulatory constraints. The following recommendations have been tabled for South Africa (Anchor Environmental Consultants 2015): 300 m in an offshore environment, 100 m in a nearshore open coast environment, 30 m in sheltered coastal environments and special management areas, 0 m for outfalls in established or proposed MPAs, the surf zone and estuaries
Semi-diurnal tides	When there are two high tides and two low tides within a day that are about the same height,
Scoping	A procedure to consult with stakeholders to determine issues and concerns and for determining the extent of and approach to an EIA and EMP (one of the phases in an EIA and EMP). This process results in the development of a scope of work for the EIA, EMP and specialist studies.
Specialist study	A study into a particular aspect of the environment, undertaken by an expert in that discipline.
Species	A category of biological classification ranking immediately below the genus, grouping related organisms. A species is identified by a two part name; the name of the genus followed by a Latin or Latinised un-capitalised noun.
Species richness	The number of different species represented in an ecological community. It is simply a count of species and does not take into account the abundance of species.
Stakeholders	All parties affected by and/or able to influence a project, often those in a position of authority and/or representing others.
Subtidal	The marine habitat that lies below the level of mean low water for spring tides.
Supratidal	The area above the spring high tide mark that is not submerged by seawater. Seawater penetrates these elevated areas only at high tide during storms.
Surficial sediments	Calculated conservatively as the upper 20 cm of sediment for the purposes of offshore disposal.

Surf zone	Zone extending seawards of the high water mark to a point where the largest waves begin to break, off any section of coast defined as “sandy coast” or “mixed coast” on the National Coastline Layer, available from the South African National Biodiversity Institute’s BGIS website (http://bgis.sanbi.org).
Trophodynamics	The dynamics of nutrition and metabolism.
Total Suspended Solids	A measure of the mass per unit volume of TSS in the water column.
Turbidity	A measure of light conditions in the water column.
Wind forcing	The movement of surface waters and the resulting transfer of energy to deeper waters by the predominant wind (i.e. a strong easterly wind will result in an eastward flowing surface current).

ABBREVIATIONS

ADCP	Acoustic Doppler Current Profiler
Anchor	Anchor Environmental Consultants
BA	Basic Assessment
BACI	Before-After/Control-Impact
BCS	Benguela Current System
BMSL	Below Mean Sea Level
CDOM	Coloured dissolved organic matter
CSIR	Council for Scientific and Industrial Research
CTD	Conductivity, temperature, depth
CWDP	Coastal Water Discharge Permit
DEA: O&C	Department of Environmental Affairs: Oceans and Coasts
DDT	Dichlorodiphenyltrichloroethane
DEAT	Department of Environmental Affairs and Tourism
DO	Dissolved Oxygen
EA	Environmental Authorisation
EIA	Environmental Impact Assessment
EMPr	Environmental Management Programme
ERL	Effects Range Low
ERM	Effects Range Median
GA	General Authorisation
GDA	General Discharge Authorisation
H_2SO_4	Sulphuric acid
ICMA	Integrated Coastal Management Act (No. 24 of 2008)
IEM	Integrated Environmental Management
IUCN	International Union for Conservation of Nature
MIA	Marine Impact Assessment
MPA	Marine Protected Area
MSL	Mean Sea Level
NBA	National Biodiversity Assessment
NAL	National Action List
NEMA	National Environmental Management Act (No. 107 of 1998, as amended)
NOAA	National Oceanic and Atmospheric Administration
NOAC	No Observed Effect Concentration
NWA	National Water Act (No. 36 of 1998)
OPBC	Oceana Power Boat Club
PAH	Poly-aromatic hydrocarbon
PNEC	Predicted No Effect Concentration
PSU	Ocean salinity is generally defined as the salt concentration in sea water. It is measured in unit of PSU (Practical SalinityUnit), which is a unit based on the properties of sea water conductivity. It is equivalent to per thousand or (o/00) or to g/kg.
RMZ	Recommended Mixing Zone
RWQ	Receiving Water Quality
SLS	Sodium lauryl sulphate

STPP	Sodium tripolyphosphate
TOC	Total Organic Carbon
TON	Total Organic Nitrogen
TRC	Total Residual Chlorine
TSP	Trisodium phosphate
TSS	Total Suspended Solids
UES	Uniform Effluent Standard
WML	Waste Management Licence
WQBEL	Water Quality Based Effluent Limits
WQG	Water Quality Guidelines
WUA	Water Use Authorisation

1 INTRODUCTION

The Department of Agriculture, Forestry and Fisheries (DAFF), as the lead agent for aquaculture management and development in South AFrica, intends to establish and manage a sea-based Aquaculture Development Zone (ADZ) in Algoa Bay in the Eastern Cape. A Sea-based ADZ usually consists of a selection of designated precincts, which provide opportunities for existing aquaculture operations to expand and new ones to be established. An ADZ provides economic benefits to the local community through job creation and regional economic diversification. ADZs are intended to boost investor confidence by providing 'investment ready' platforms with strategic environmental approvals and management policies already in place, allowing commercial aquaculture operations to be set up without the need for lengthy, complex and expensive approval processes. It is anticipated that an ADZ will create incentives for industry growth, provide marine aquaculture services and enhance consumer confidence.

Aquaculture is one of the sectors which form part of Operation Phakisa under the Ocean's Economy in South Africa. Operation Phakisa is an initiative of the South African government which aims to implement priority economic and social programmes better, faster and more effectively. Operation Phakisa was launched by the President of the Republic in October 2014. The sector offers significant potential for rural development, especially for marginalised coastal communities. The proposed development will provide employment opportunities for the local and regional communities.

In 2009 a Strategic Environmental Assessment (SEA) was undertaken for the entire South African coastline to identify suitable aquaculture precincts. In this assessment the Eastern Cape was highlighted as an area holding potential for the establishment of ADZ. As part of a finer-scale SEA undertaken by DAFF in 2011, two precincts, namely Algoa 1 and 5 were identified as the most promising alternative precincts. Environmental Authorisation (EA) was granted for Algoa 1 on 9 July 2014 following a lengthy Environmental Impact Assessment (EIA) process, which was initiated in 2010. During the appeals process, which followed the positive decision, a total of twenty eight (28) substantive appeals were lodged against the decision. In response, the Minister of Environmental Affairs issued a decision on the Appeal suspending the EA to allow for further studies to be undertaken.

In mid-2016, DAFF commissioned three comparative assessments, including a detailed feasibility study, a socio-economic assessment and a marine ecological assessment for Algoa 1 and 5 (these three studies have been included as stand-alone documents in Appendix D of this Basic Assessment Report). The economic feasibility study found that conditions at Algoa 5 are sub-optimal for economic aquaculture and mitigation measures would be impractical or uneconomic to implement, which renders the proposed site not economically competitive (Britz and Sauer 2016b). Furthermore, the Addo Marine Protected Area (MPA) was recently approved by cabinet and no longer excises Algoa 5 from the MPA (note that the Gazette Notice from 2016 excluded Algoa 5 from the boundaries of the MPA). This site can therefore no longer be legally excised from the MPA. For the reasons described above, Algoa 5 was screened out and is not taken forward as a potential precinct in the current Basic Assessment process.

DAFF has since withdrawn the original application for environmental authorisation and intends to submit a new application for the development of the ADZ for which a Basic Assessment process is required in terms of the 2017 EIA Regulations promulgated in terms of the National Environmental Management Act (Act 107 of 1998). DAFF intends for the ADZ to accommodate finfish as well as bivalve culture (oysters/mussels) within a combination of precincts. DAFF has appointed Anchor Research and Monitoring Pty. Ltd. (Anchor) to undertake the BA Process and application for EA.

The precincts considered in this application include one precinct from the previous process (Algoa 1), and two new precincts, designated as Algoa 6 and 7 (Figure 1.1). Algoa 6, situated near the Port Elizabeth Harbour, was identified but screened out in the scoping phase of the original EIA (2010-2014) which focussed only on finfish culture, and is now been put forward as a suitable site for bivalve production in this new (2019) application process. Algoa 7 is a new precinct located directly in front of the Ngqura harbour that has been identified as a potential site for finfish culture. This site has undergone an internal feasibility assessment in which it was found to be suitable in terms water depth, shipping traffic, and accessibility (i.e. financial considerations). This site overlaps with the recently approved Addo Marine Protected Area (MPA) but the Department of Environmental Affairs Branch Oceans and Coasts has indicated that the affected portion of this site could potentially be excised should Environmental Authorisation be granted for this precinct. Thus, in this application process, two sites, Algoa 1 and 7, are being put forward for finfish culture , while one of these, Algoa 1, along with a third site, Algoa 6, is being put forward for bivalve culture (Figure 1.1).

DAFF appointed Anchor Research and Monitoring Pty. Ltd. (Anchor) to undertake benthic mapping and habitat analysis for Algoa 7, and to conduct dispersion modelling of water quality and organic waste from the mariculture operations. This is to determine potential risks posed by the use of this site on the planned land-based COEGA Aquaculture Development Zone and adjacent conservation areas, and to better understand risks that future maintenance and expansion activities within the harbour may pose for the proposed aquaculture site.

The benthic mapping and habitat analysis and modelling study informs the marine specialist study and the Basic Assessment Report that will be submitted to National Department of Environmental Affairs (competent authority for this project). This report presents and discusses the results of the dispersion modelling component and represents the second report for the above-described project (Project code: 1817, report number 2).

1.1 Terms of Reference

Numerical dispersion modelling studies provide an estimation of 1) dilution rates for key contaminants (e.g. organic waste) and 2) the expected footprint of the plume in the marine environment. This will enable likely impacts of the operation of the proposed fish cages to be quantified in relation to the COEGA Aquaculture Development Zone (specifically Algoa 6 and Algoa 7, see Figure 1.1) and adjacent conservation areas. The modelling should further inform recommendations for suitable tonnages, zones or site.

As such, specific ToR for the dispersion modelling phase of the project includes:

1. Build and run a water quality and organic matter dispersion model for the proposed finfish areas (Algoa 1, and Algoa 7); and,
2. Make recommendations for suitable tonnages, zones or site according to the results of the modelling.

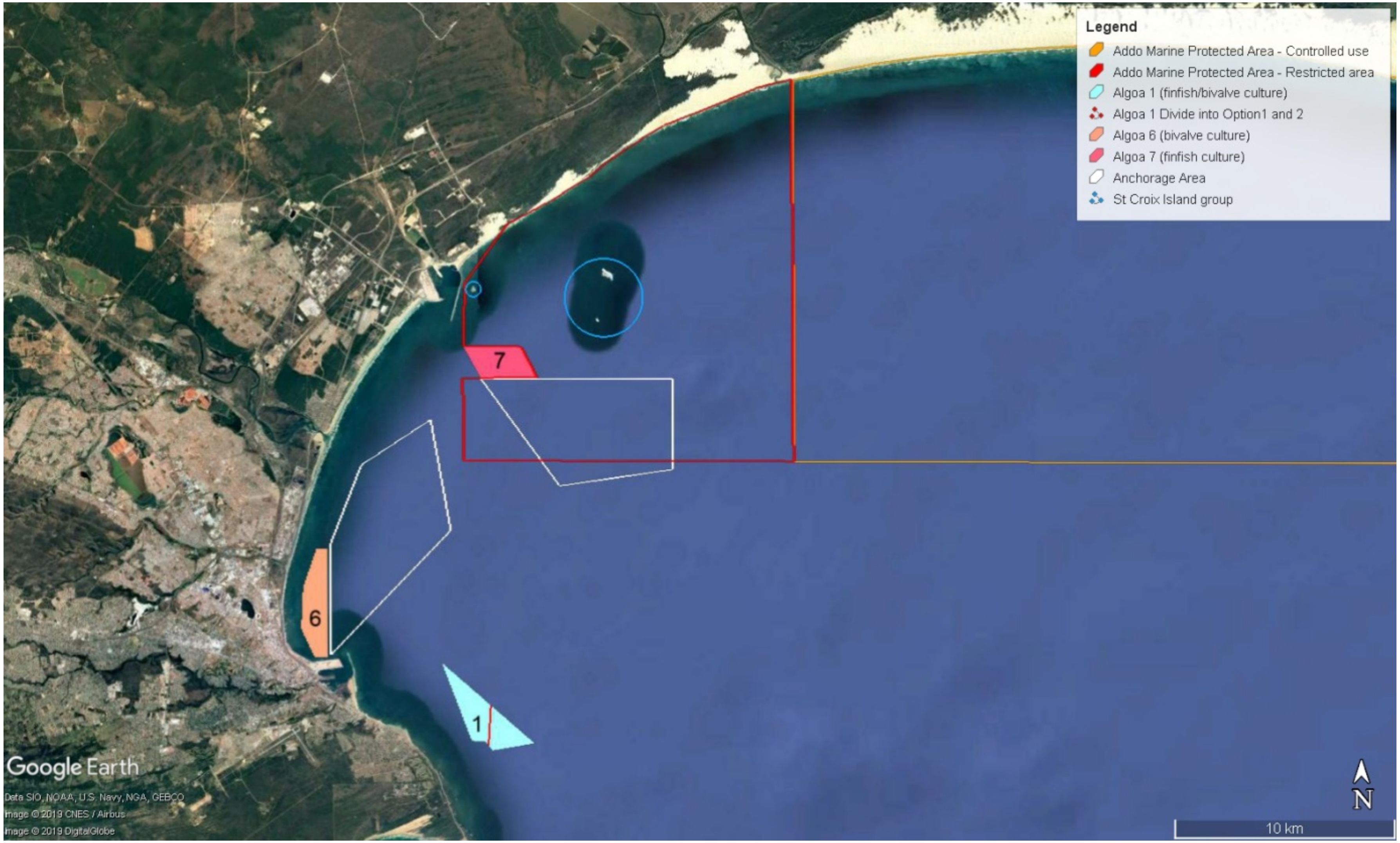

Figure 1.1 **Precincts considered during the 2019 application for environmental authorisation for a sea-based Aquaculture Development Zone in Algoa Bay, Eastern Cape. Precincts 1, 6 and 7 constitute feasible precincts and have been considered during the present Basic Assessment process. Department of Environmental Affairs Branch Oceans and Coasts has indicated Algoa 7 could potentially be excised from the Addo Marine Protected Area should Environmental Authorisation be granted for this precinct.**

2 DISPERSION MODELLING

2.1 Legislative context for pollution control in South Africa

Contemporary coastal water quality management strategies employed around the world, including in South Africa, focus on maintaining or achieving receiving water quality such that the water body remains or becomes fit for all designated uses. Designated uses (sometimes also referred to as "beneficial uses") of coastal and marine waters include the protection of the natural environment (i.e. organism and ecosystem health), mariculture (land-based and in situ), industrial activities, and recreation (including harvesting of seafood and contact recreation). Water quality requirements for these different user groups are not necessarily the same, and in some instances, they may even conflict. These differences imply that water quality that is adequate for one specific user group may not be suitable for another. Water quality is thus not an intrinsic property of water, but is linked to its use. A definition of what constitutes fitness for use is thus a key issue in the evaluation and management of water quality. This goal oriented management approach arose from the recognition that enforcing end of the pipe effluent standards in the absence of an established context, i.e. not recognising the assimilative capacity and requirements of receiving environments, would reach a point where water bodies would only be marginally fit for their designated uses. This approach is referred to as the 'receiving water quality framework (RWQF) approach.

The Department of Water and Sanitation (DWS) developed a set of four Water Quality Guidelines in 1992, updated in 1995 that were aimed at managing coastal marine water quality for designated uses. These guidelines include:

- Volume 1: Natural Environment
- Volume 2: Recreational Use (updated and launched by the DEA in 2012)
- Volume 3: Industrial Use
- Volume 4: Mariculture

Responsibility of managing coastal waters was transferred to the Department of Environmental Affairs, Branch Oceans and Coasts (DEA: O&C) in terms of the Integrated Coastal Management Act (ICMA), which was promulgated in February 2009. The 1995 South African Water Quality Guidelines for Coastal Marine Waters (hereinafter referred to as '*the 1995 Guidelines*') contain narrative statements and guideline values along with relevant background information (e.g. description, source, fate in the environment, occurrence in South African marine waters etc.) for 29 seawater properties and constituents. The 1995 Guidelines were updated in 2015 (see Anchor 2015).

2.1.1 Water quality guidelines

There are a wide variety of legal instruments that are utilised by countries to maintain and/or achieve WQGs in the receiving environment. These include setting appropriate contaminant limits, the banning or restricting of certain types of discharges in specified areas, prohibiting or restricting discharge of certain substances, as well as providing financial incentives to reduce pollution at the source alongside the implementation of cleaner treatment technology. The only effective method, however, that ensures compliance of an effluent with water quality guidelines/standards is to determine site-specific effluent limits that are calculated based on the WQGs (or standards) of a given water body, the effluent volume and concentration, as well as the site-specific assimilative capacity of the receiving environment. This method is also identified as the water quality based effluent limits (WQBEL) approach (Anchor 2015) and recognises that effluent (and its associated contaminants) is rapidly diluted by the receiving waters as it enters the environment. In order to take advantage of this beneficial effect, allowance is generally made for a RMZ which extends a short distance from the outfall point (or pipe end) and is an area in which contaminant levels are allowed to exceed the established WQGs (or standards) for the receiving environment. The magnitude of the RMZ should, in theory, vary in accordance with the sensitivity and significance of the receiving environment and the location of the outfall point in the environment, but in practice is usually set at a distance of around 100 m from the pipe end for marine systems. The WQBEL approach differs from the Uniform Effluent Standard (UES) approach in which fixed maximum concentrations or loads are applicable for contaminants in wastewater discharges for all users or outfalls, irrespective of where they are located (Anchor 2015).

South Africa has adopted the RWQ framework for the management of water quality in both inland (freshwater) and marine water bodies and uses both the WQBEL and the UES approaches to implement the framework. Receiving water quality guidelines have thus been published for the full range of beneficial uses for inland water (human consumption, aquaculture, irrigation, recreational use, industrial use, and protection of biodiversity and ecosystem functioning) and also for the marine environment (aquaculture, recreational use, industrial use, and protection of biodiversity and ecosystem functioning) (see Table 2-1 and Table 2-2).

Table 2-1 Specific water quality for other beneficial use areas as per DWAF (1995).

Recreational use of marine waters (DWAF 1995)	
Full contact recreation	Activities such as swimming, diving (scuba and snorkelling), water skiing, surfing, paddle skiing, wind surfing, kite surfing, parasailing and wet biking.
Intermediate contact recreation	Activities such as boating, sailing, canoeing, wading and angling, where users may come into contact with the water or swallow water.
No-contact recreation	All recreational activities taking place in the vicinity of marine waters, but which do not involve direct contact, such as sightseeing, picnicking, walking, horse riding etc.
Basic amenities	Aesthetically acceptable environment.
Mariculture	Refers to the farming of marine and/or estuarine organisms in land-based (i.e. ‘off-stream’ tanks using pumped seawater) or water based (i.e. ‘in stream’) systems.
Industrial uses	Waste water discharges, cooling water, desalination, and aquariums.

Table 2-2 Water quality guidelines for physio-chemical properties of seawater as contained in the 1995 South African Water Quality Guidelines for Coastal Marine Waters: Volume 1: Natural Environment.

Parameter	WQGs	
Temperature	The maximum acceptable variation in ambient temperature is + or - 1°C.	
Salinity	The target range for the South African coastal zone is 33-36 ppt.	
Suspended solids	The concentration of suspended solids should not be increased by more than 10% of the ambient concentration.	
pH	The target range for the South African coastal zone is 7.3-8.2	
Colour/Turbidity/Clarity	Turbidity and colour acting singly or in combination should not reduce the depth of the euphotic zone by more than 10 % of background levels measured at a comparable control site. The colour (substances in solution) of water should not exceed background levels by more than 35 Hazen units.	
Dissolved oxygen	For the south and east coasts the dissolved oxygen should not fall below 5 mg/L (99 % of the time) and below 6 mg/L (95 % of the time).	
Dissolved nutrients (mg/l) Phosphates: PO_4-P Nitrogen: NO_2^-, NO_3 and NH_3	Should not cause excessive algal growth and the loads should not exceed the levels which are introduced by natural processes such as upwelling.	
Ammonia (mg/l)	0.02mg N as NH_3; 0.60 mg N as $NH_3 + NH_4^+$	
Toxic inorganics (mg/l)	Arsenic (AS)	0.012
	Cadmium (Cd)	0.004
	Chromium (Cr)	0.008
	Copper (Cu)	0.005
	Lead (Pb)	0.012
	Mercury (Hg)	0.003
	Nickle (Ni)	0.025
	Silver (Ag)	0.005
	Zinc (Zn)	0.025

2.2 Aquaculture pollution management

2.2.1 Legislation and management of aquaculture development

The 2009 SEA (Jooste 2009) identified the following Draft Policy Documents as relevant to mariculture development in South Africa:

1. Policy and Guidelines for Fin Fish Farming, Marine Aquaculture experiments and Pilot Projects in SA. DEAT 2006, 2007.
2. Guidelines for Mariculture Ranching in South Africa. DEAT 2006, 2007.
3. Marine Aquaculture Sector Development Plan 2006, 2007.

The final Marine Aquaculture Policy document was published by DEAT in 2007, namely, "Policy for the development of a Sustainable Marine Aquaculture Sector in South Africa" (Government Gazette No. 30263 September 2007). The policy explicitly states that "The National Environmental Management Act (NEMA), Environmental Impact Assessment (EIA) requirements will still be applicable". In order to avoid possible conflicting use, the policy outlines that the development of an ADZ should take cognizance of other marine activities such as tourism, fishing and recreational activities, as well as area management initiatives such as MPAs. The 2007 marine aquaculture policy gave rise to a "Marine Aquaculture Policy Implementation Plan 2009-2014" (DEAT MCM 2009).

2.2.2 Water quality impacts of sea-based cage mariculture

The impacts of fish farming on the marine environment globally have been well studied. One of the primary impacts of mariculture cage farming is that untreated wastes resulting mainly from uneaten food and faeces from fish in sea cages are discharged directly into the sea, and represent a potentially significant source of nutrients (Brooks *et al.* 2002, Staniford 2002a). Studies have documented elevated dissolved nutrients and particular components (POC and PON) both below, and in plumes downstream, of fish cages (Pitta *et al.* 2005). These wastes can impact both on the benthic environment and on the water column. Sediments and benthic invertebrate communities under fish farms often show chemical, physical and biological changes attributable to nutrient loading. Elevations in carbon, ammonia and hydrogen sulphide concentrations are frequently observed (Carroll *et al.* 2003). Nutrient enrichment and resulting eutrophication of sediments under fish cages is regarded as a serious issue in some areas (Staniford 2002b). Impacts on benthic habitats below fish cages does, however, tend to be localized to the area under the cages, but recovery has been observed to take up to fifteen months after the closure of a fish farm. Most studies indicate that the effect is usually contained within a few hundred meters (i.e. Porrello *et al.* 2005), but one Mediterranean study was able to detect changes up to 1000 m away (Sarà *et al.* 2004). The extent of contamination of the sediments under fish cages is obviously highly site and project specific. Nearshore marine environments with low flushing rates and/or sediments susceptible to organic loading, should be avoided when selecting sites for finfish cages. Cages should also be placed in water of sufficient depth to allow flushing and to reduce the build-up of wastes directly below cages. Fallowing is the standard mitigation method used to allow recovery of sediments below fish farms in Scotland (Black *et al.* 2004). Feeding by wild fish on the wastes and uneaten food below cages has also been shown to mitigate the impacts of waste on benthic environments. Some studies have reported that 40-80% of the uneaten food and waste falling out of cages was eaten by wild fish (Vita *et al.* 2004, Felsing *et al.* 2005). This in turn, however, may increase the risk of parasite and disease transmission to wild stocks and may also attract piscivores to cages with the associated problems.

Nutrient loading of the water column along with the reduction of dissolved O_2 concentrations as a result of fish cages can also stimulate harmful algal blooms, which pose a threat human health and mariculture operations (Gowen & Ezzi 1992, Navarro 2000, Ruiz 2001, all cited in Staniford 2002a).

A modelling study of nutrient discharges from yellowtail (*S. lalandi*) farms in Australia indicates that this species may have a significantly higher eutrophication impact than other cultured finfish species (Fernandes & Tanner 2008). This species is amongst the most likely to be utilized in Algoa Bay ADZs and in combination with the relatively sluggish currents within the bay, the probability of negative benthic and water quality impacts is high. The amount of settable faecal solids, total nitrogen and total phosphorus, however, appears highly dependent on the type (brand, size, floating/sinking) and quality of pellet feed used (Moran *et al.* 2009). Modelling of waste (nutrient and chemical) dispersal from a single proposed commercial scale fish farm at Mossel Bay (an area with similar current speeds to Algoa Bay) has been conducted (Mead *et al.* 2009). Settable waste was expected to sink to the sea floor within 200 m of the cages (Mead *et al.* 2009). However, this study did indicate that elevated levels of dissolved nutrients would likely occur up to 2 km from the fish cages, with nitrate levels expected to be above background concentrations 8-12 km from the site under certain oceanographic conditions despite a very efficient assumed Food Conversion Ratio (FCR) of 1.2 (Mead *et al.* 2009).

FCR is the conventional measure of animal husbandry production efficiency i.e. the weight of feed administered over the lifetime of an animal divided by weight gained. Lower FCR values indicate higher efficiency. Feed is one of the largest costs to an aquaculture farm, and better feed conversion means less food to produce more fish i.e. a better FCR results in a more profitable enterprise. The FCR also allows for an estimate of the feed that will be required in the growing cycle, providing input into feed selection and use to maximize profitability. FCR can be improved in part by the type of feed used and the feeding rate, but is also dependent on the species of fish farmed — some fish species have an inherently better FCR than others, due to physiology and behaviour.

Mitigation (as outlined by Anchor & CapeEPrac 2013) includes the use of species and system-specific feeds designed to maximize food conversion ratios and minimize waste, rotation of cages within a site to allow recovery of benthos, and sensible site selection (sufficient depth, current speeds and suitable sediment type).

2.2.3 Simulation models

In general, reducing impacts involves better farming practices, improved feeds and the location of fish farms in more exposed areas to improve dilution rates (Stigebrandt *et al.* 2004). In addition, impacts can be further reduced through the implementation of standardised monitoring programmes, adaptive management and the use of simulation models (Stigebrandt *et al.* 2004, Rosenthal 2001). These mathematical models have been designed specifically to simulate key aspects of marine fish farming, such as rates of water renewal in tanks and net pens that are necessary to ensure high water quality (Stigebrandt *et al.* 2004, Stigebrandt 1986; McDonald *et al.* 1996). Simulation models (which include models for numerical dispersion) are useful tools for:

1. rational, evidence based coastal zone planning;
2. estimating the holding capacity of sites for fish farming;
3. maintaining high water quality in net pens; and,
4. evaluating how changes in farm management are likely to affect surrounding areas.

In general, there are three classes of simulation models - models that simulate the dispersion and bottom deposition of organic particles from fish farms (Gowen *et al.* 1988, Silvert 1992, Kishi *et al.* 1994, Stigebrandt & Aure 1995, Hevia *et al.* 1996, Panchang *et al.* 1997 and Cromey *et al.* 2002); models that describe and predict the impact of organic material on the sediment or the benthic infauna (Stigebrandt & Aure 1995, Findlay & Watling 1997 and Cromey *et al.* 1998); and models that have been developed to estimate the eutrophication effects of fish farming on inshore water bodies that also receive nutrients and organic matter from other sources (Aure & Stigebrandt 1990).

2.3 Methods

For this study, modelling involved the use of the Ancylus MOM (3.2) model which was aimed at determining carrying capacity, organic enrichment and benthic interactions.

Ancylus MOM (3.2) is a model that was developed as part of the Norwegian MOM system. The MOM management system (Modelling—Ongrowing fish farms—Monitoring) has been used by the Norwegian authorities for environmental regulation of fish farming for over a decade, and is designed for observation, prediction, and regulation of the local environment impact of intensive marine fish farming (see Ervik *et al.* 1997 and Hansen *et al.* 2001). The MOM system focusses on organic enrichment. The ultimate environmental objective of the MOM management system is to manage a site for fish farming in a way that the impacts of such activities do not exceed threshold levels that safeguard the wellbeing of both the farmed fish and the environment (Stigebrandt *et al.* 2004).

The environmental effects of fish farming on the surrounding water and on water quality in the farm were estimated using oxygen and ammonium concentrations in the farm and oxygen concentrations at the bottom below the farm as proxy variables (ECASA toolbox, www. ecasatoolbox.org.uk/the-toolbox/eia-species/models/data.../mom_fish. pdf). The model also calculates nutrient release from the farm to the surface water. Holding capacity of the farm was expressed as the maximum of the Total Fish Production (TPF) based on oxygen and ammonium concentrations in the cages and oxygen concentration in the bottom water. To achieve this, the model integrates fish, water quality, dispersion and benthic models. A brief description of the model is outlined below. The mathematical description of the model is given by Stigebrandt *et al.* (2004).

2.3.1 Assumptions

Ancylus MOM computes the holding capacity of a specified area according to the Norwegian MOM system for range of fish species. The model comprises four sub-models which, for a given set of local environmental parameters, compute holding capacity according to these three basic requirements. Input variables include (as per Stigebrandt *et al.* 2004) local environmental properties such as water depth, the annual temperature cycle and the vertical distribution of current as well as concentrations of oxygen and ammonia (NH_3)and maximum fish density per unit area (and therefore the configuration of the farm), feeding rate and feed composition.

Figure 2.1 below presents an overview of the MOM model. A general fish sub-model computes the metabolism, growth and feed requirement of a specified fish stock, which is dependent on the weight of the fish and the temperature of water (Stigebrandt 1999, Stigebrandt *et al.* 2004). The MOM model computes consumption of food and oxygen, production of faeces and excretion of ammonium depending on a given food composition.

Caged fish require sufficiently high oxygen concentrations and sufficiently low ammonia (NH_3) or UIA (unionised ammonium) concentrations for optimal survival and growth. Stigebrandt & Aure (1995) describe the dispersion model used in MOM that computes the distribution of particulate matter from the net pens to the bottom, while a benthic sub-model computes the maximum rate of particulate matter sedimentation that will result in the survival of the benthic communities beneath the cages. From a given lowest current speed in the surface layer, MOM computes maximum fish biomass and fish production for each month under the prerequisite of good oxygen and ammonia conditions in the cages, as per Stigebrandt *et al.* (2004). Outputs for the MOM model (expressed per tonne of fish) include concentrations of the dissolved oxygen and phosphorous, and carbon flux to the sediment (including sediment concentrations of oxygen and phosphorous).

A limitation with MOM is that should the current standard deviation (i.e. how the current fluctuates over time) exceed 3.5 $cm.s^{-1}$, the model assumes that possible deposits on the benthos are flushed by intermittent strong currents, and the maximal carbon flux to the sediment is set by the model as 0 $gC/m^2/yr$). This implies that the model assumes that current standard deviation exceed 3.5 $cm.s^{-1}$ results in no benthic impact, which may not necessarily be true.

The global production of bivalves has grown from around 1 million tonnes in 1950 to 16.1 million tonnes in 2015 (FAO 2018), with just over half of the volume derived from aquaculture production (McKindsey *et al.* 2011). Bivalve aquaculture accounts for roughly 27% of global aquaculture production and provided approximately 13 % of the total fish produced for human consumption worldwide in 2006 (FAO 2018). The rapid growth of the industry has raised concerns about the ecological and physico-chemical impacts of aquaculture on local environment (Black 2001) and numerous studies have been conducted to help better understand the ecological role played by culturing activities (Davenport *et al.* 2003; Holmer *et al.* 2008, National Research Council 2010). Ecological studies of bivalve aquaculture recognise three primary methods that culturing of bivalves can impact the ecosystem: 1) material processes – the consumption of food and production of waste, 2) physical structure – the introduction of artificial substrate in the form of structures and anchoring and the introduction of the aquaculture species itself, and 3) pulse disturbances as result of harvesting efforts (Dumbauld *et al.* 2009). Suspended cages or longlines, the method commonly used for bivalve mariculture in South African, reduces the impacts of pulse disturbance because harvesting and maintenance is conducted from on board a boat during which there is no additional physical contact with the benthos. This off-bottom method is however more susceptible to biofouling (Shumway & Whitlatch 2011) but the impacts of this can be mitigated by appropriate planning and management, which if conducted with enough regularity can prevent biofouling species from significantly altering the benthic community (Forrest *et al.* 2009). Many studies have focused on the role of bivalve biodeposition in changes to the benthos. These largely report that impacts are localised and negligible by comparison to other aquaculture activities, such as finfish cages (Forrest *et al.* 2009). Known as extractive species, the feeding habits of bivalves actually remove waste materials from the water column and generally have a positive influence of the water quality of the surrounding system (National Research Council 2010, FAO 2018). It is for these reasons that no modelling was done for the proposed ADZ Algoa 6 where only bivalve farming is being considered.

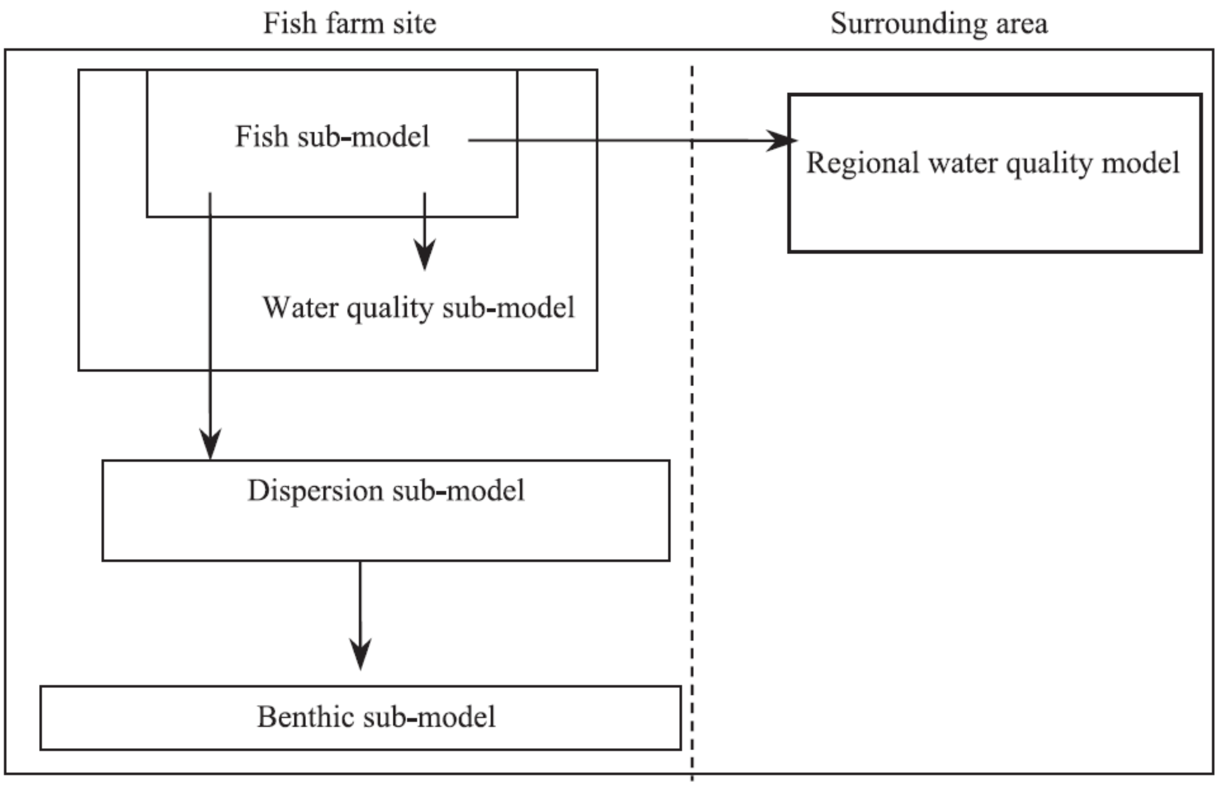

Figure 2.1 **Overview of the MOM model system from Stigebrandt *et al.* (2004). The local site model is linked to a regional (inshore) water quality model (Aure & Stigebrandt 1990). The output parameters from the fish sub-model are used as input parameters to the water quality sub-model, the dispersion sub-model and the regional water quality model. The dispersion sub-model delivers input parameters to the benthic sub-model. All sub-models require input parameters describing various environmental conditions at the farm site and of the inshore water body.**

2.3.2 Ambient currents

The current conditions in a farm are crucial for health of both the farmed fish and for the benthic community below. Long periods without flushing result in the worst water quality scenario within the cages, while water quality at the bottom is dependent both on the variability of currents (which determines the dispersion of particulate matter) and on the minimum current in the bottom layer that supplies oxygen to the benthic animals.

Current roses depicting strength, frequency and the direction of currents measured by Acoustic Doppler Current Profiler (ADCP) instruments for Algoa 1 and Algoa 2 are shown in Benthic Mapping and Receiving Environment report. Algoa 1 data was collected between 2 February 2013 and 11 June 2013, and Algoa 2 data was collected between 20 February 2012 and 19 December 2012. The nearest available ADCP data for Algoa 2 was used as a proxy for Algoa 7. These data included measurements for up to 10 depth bins within the water column, as well as measurements for a near-surface (0-6m) dynamic cell, that moved with the tide, and enabled quantification of typical current velocities and directions under the prevailing wind conditions and served as input data into the model.

The current data values used for the model are shown in Table 2-3. The dispersion of particulate matter is determined by the fluctuating component of the current (Stigebrandt *et al.* 2004). A measure of this is the standard deviation (std dev = σ "sigma") which is estimated from the variance sigma (σ^2). If a current record is composed of M current registrations u_i (i=1.M) and the mean current of the record is u_0, then σ is defined by

$$\sigma = \sqrt{\frac{1}{M}\sum_{i=}^{M}(u_i - u)^2}$$

As per Stigebrandt *et al.* (2004), current measurements obtained at mid-depth (~15m) and perpendicular to the main axis of the farm (i.e. southerly currents for Algoa 1 and south westerly currents for Algoa 7) were used for the estimate of σ (Table 2-3).

Given that the MOM model assumes the maximal carbon flux to the sediment as 0 gC/m^2/yr should the current standard deviation exceed 3.5 cm.s^{-1}, the 10th percentile current speed data was included in the determination of σ, given that these conditions can be assumed to represent the worst-case scenario (i.e. 90% of the time, current standard deviation exceeds the 3.5 cm.s^{-1} threshold, and maximal carbon flux to the sediment is 0 gC/m^2/yr) (see Table 2-3).

Table 2-3 Current data values used for the model.

	Units	Algoa 1	Algoa 7
Average current speed surface	$cm.s^{-1}$	53.73	9.23
Average current speed middle	$cm.s^{-1}$	11.15	8.26
Average current speed bottom	$cm.s^{-1}$	8.77	6.83
σ	$cm.s^{-1}$	7.57	7.24
10th percentile surface current	$cm.s^{-1}$	21.4	2.60
10th percentile bottom current	$cm.s^{-1}$	2.80	2.30
10th percentile σ	$cm.s^{-1}$	0.93	0.66

2.3.3 Ambient constituents

The parameters shown in Table 2-4 were included as background concentrations Algoa 1 and Algoa 7 (see the Benthic Mapping and Receiving Environment report in Appendix D of the Basic Assessment Report). Ammonia concentration values were obtained from analysis of water samples collected during a field survey in October 2018. Values recorded elsewhere within Algoa Bay were deemed acceptable as background levels (i.e. average dissolved oxygen concentrations recorded for Algoa 1 were used for Algoa 7, see Table 2-4). Given the proximity of the sites and the open nature of Algoa Bay, these values are expected to be sufficient for modelling purposes.

The average monthly sea surface temperature (°C) for Algoa Bay as used in the model are from in-situ monitoring conducted during earlier ADZ assessments and are presented in the Benthic Mapping and Receiving Environment report (Appendix D). Salinity was assumed as 35.2 PSU (as per Schumann 1998).

Table 2-4 Ambient concentration values (mg/l) used in this model.

Parameter	Unit	Background/Ambient Concentration	
		Algoa 1	Algoa 7
Salinity	PSU	35.2	
Total ammonia nitrogen	**mg/l**	0.22	0.14
Oxygen	mg/l	7.11	

2.3.4 Critical concentrations

Stigebrandt *et al.* (2004) specifies that carrying capacity is estimated by the model in terms of maximum fish production, on the premise that:

1. the benthic fauna beneath the farm site must not be allowed to disappear due to accumulation of organic material;
2. the water quality in the net pens must be kept high; and,
3. the water quality in the areas surrounding the farm must not deteriorate.

Dissolved oxygen concentration (DO) and unionised ammonia (NH_3), or UIA, are considered the most important water quality variables in fish culture. The sensitivity to low oxygen concentrations and high ammonia concentrations varies between fish species. A brief description of the fate and impact of these two constituents in the marine environment is presented below.

Ammonia

The concentration of ammonium/ammonia in seawater exhibits considerable spatial and temporal variations, which can be attributed to the complex processes that determine its fate in the marine environment. Ammonium (NH_{4+}) is formed by the protonation of ammonia (NH_3). In the marine environment, the relative concentration of these two compounds depends largely on the pH and temperature of the water body. Ammonia is uncharged and lipid soluble and therefore acutely toxic to marine organisms at low concentrations. In contrast, the hydrated ammonium ion is non-toxic and an important nutrient for primary producers. The permeability of plasma membranes to charged particles, such as ammonium ions, is relatively low.

In oxygenated unpolluted seawater samples, total ammonia nitrogen (TAN) rarely exceeds 70 µg/L (Anchor 2017). In deep anoxic stagnant water, such as in the Black Sea, ammonium concentrations can be as high as 2100 µg/L. Levels of ammonia in estuaries can also reach very high levels due to natural and anthropogenically-linked contributions from the catchment (>1 mg/L) especially in systems that receive large volumes of organically rich effluent (e.g. from WWTWs). In the absence of anthropogenic inputs, ammonia levels in estuaries and inshore marine waters are generally less than 50 µg/L (Grasshoff *et al.* 1976, Day 1981, Allanson & Baird 1999). Measured TAN in Algoa was somewhat higher than these typical values (Table 2-4).

Dissolved oxygen

Biochemical Oxygen Demand (BOD, also called Biological Oxygen Demand) is the amount of dissolved oxygen needed (i.e. demanded) by aerobic biological organisms to break down organic material present in a given water sample at certain temperature over a specific time period. When BOD levels are high, dissolved oxygen (DO) levels decrease because the oxygen that is available in the water is being consumed by the bacteria. The dissolved oxygen of water is a non-conservative property. The solubility of oxygen in water is largely dependent on the salinity and temperature of the water.

DO is an essential requirement for most heterotrophic marine organisms. Natural levels in seawater are largely governed by local temperature and salinity regimes, as well as by organic content. Coastal upwelling regions are frequently exposed to hypoxic conditions owing to extremely high primary production and subsequent oxidative degeneration of organic matter.

Hypoxic water (defined as concentrations of less than 2 millilitres of oxygen per litre) has the potential to cause mass mortalities of benthos and fish (Diaz & Rosenberg 1995). Marine organisms respond to hypoxia by first attempting to maintain oxygen delivery by increasing respiration rates, by increasing the number of red blood cells, or by increasing the oxygen binding capacity of haemoglobin. They then start conserving energy through metabolic depression, down regulation of protein synthesis and modification of certain regulatory enzymes and eventually resort to anaerobic respiration upon exposure to prolonged hypoxia (Wu 2002). As a result, hypoxia reduces growth and supresses feeding, which may eventually affect individual fitness. The effects of hypoxia on the reproduction and development of marine animals remains almost unknown. Many fish and marine organisms can detect, and actively avoid hypoxia as seen during rock lobster "walk-outs" and migration of macrobenthos from their burrows to the sediment surface, rendering them more vulnerable to predation. Hypoxia may eliminate sensitive species, thereby causing changes in species composition of benthic fish and phytoplankton communities. Decreases in species diversity and species richness are well documented, and changes in trophodynamics and functional groups have also been reported. Under hypoxic conditions, there is a general tendency for suspension feeders to be replaced by deposit feeders, demersal fish by pelagic fish and macrobenthos by meiobenthos (Wu 2002). Further anaerobic degradation of organic matter by sulphate-reducing bacteria may additionally result in the production of hydrogen sulphide, which is detrimental to marine organisms (Brüchert *et al.* 2003).

Critical values for DO and UIA are given in Table 2-5 below. Table 2-6 indicates the WQGs at the edge of the RMZ for parameters included in this dispersion model. The South African Water Quality Guidelines for Coastal Marine Waters provide an ammonia guideline of 42.86 µM (0.6 $mg.l^{-1}$) (CSIR 2018). However, based on available literature on the known toxicity of ammonia in marine systems, there is general agreement that this ammonia guideline is too high (CSIR 2018), and that the standard of 0.1 $mg.l^{-1}$ ammonia included in the Australian and New Zealand Environment Conservation Council (ANZECC 2000) guidelines is more appropriate. These values are in line with the water quality classification criteria for ammonia defined by CSIR (2018).

Table 2-5 Critical concentrations (mg/l) within the cages to permit successful mariculture operations.

Parameter	Unit	Critical Concentration (as per Ervik *et al.* 2008)
Highest acceptable ammonia (NH_3) concentration	mg/l	0.03
Lowest acceptable oxygen concentration in cages	mg/l	5
Lowest acceptable oxygen concentration at cage bottom	mg/l	1

Table 2-6 Water quality guidelines at the edge of the Recommended Mixing Zone (RMZ) for parameters included in this dispersion model.

Parameter	Unit	Algoa 1	Algoa 7
N (of ammonia NH_4 plus NH_3)	mg/l	0.1	

2.3.5 Farm data

2.3.5.1 Bathymetry

The bathymetry of Algoa 1 and Algoa 7 are presented in the Benthic Mapping and Receiving Environment report. Note that results were obtained for ecological assessment and dispersion modelling purposes only and do not necessarily meet engineering specifications.

2.3.6 Fish and feed data

The levels of dissolved and particulate nutrient waste input into the surrounding environment through mariculture operations is dependent predominantly on the species of fish farmed, and the composition of the artificial food utilised. As per Stigebrandt *et al.* (2004):

"Fish and feed are described by their contents of protein, fat, carbohydrates, ashes and water and their contents of phosphorus and nitrogen. Oxygen consumption due to fish respiration and the emission of various dissolved substances from the fish are computed on the basis of size and number of fish, feed composition, feeding rate and temperature. The emissions of particulate organic matter (uneaten feed and faeces) and plant nutrients (P and N) from a farm are also computed."

While modelling the typical parameters for salmon (*Salmo salar*) would allow direct comparison with the PRDW & Lwandle Technologies (2017) Saldanha Bay ADZ modelling study, there is concern regarding the feasibility of salmon mariculture in the warm Algoa Bay waters. Therefore, we modelled the following species (see Table 2-7):

1. Yellowtail (*Seriola lalandi*); and
2. Meagre (*Argyrosomus regius*)

Both of these species are well studied and widely farmed mariculture species around the world, and good baseline and life history data are therefore available in the existing literature for these species. Meagre is a species similar to South African kob (*Argyrosomus japonicas* and *A. inodorus*), and represents a good proxy for the farming of South African kob species in Algoa Bay.

The feed Skretting Nova ME was used as the basis for input into the dispersion model as per Moran *et al.* (2009) (Table 2-8). Skretting Nova ME has been well studied in New Zealand *S. lalandi* mariculture (Moran *et al.* 2009).

Concerns have been raised that buoyant wastes may be dispersed by prevailing south easterly or southerly winds, and particularly if these would pose any danger to bathers should these buoyant wastes reach the swimming beaches in the vicinity of the ADZ. The ADCP current measurements cannot take the movement of the very surface wind-blown layer into account, and hence any modelling will not take this into account. However, it must be noted that these buoyant wastes are likely to comprise of oils or fats and that these typically pose little danger to human health. Human health concerns in the marine environment are generally related to microorganisms such as bacteria, viruses and parasites. Contaminated water can be ingested during contact sports and result in gastrointestinal illnesses. *Escherichia coli* and Enterococci are generally used as indicators for the presence of these harmful microorganisms. It is important to note that finfish farms are not a source of bacteria, viruses and parasites that could harm humans. Harmful microorganisms are excreted by warm-blooded animals (e.g. cow, pig, ostrich, humans etc.) and are washed into the sea via rivers, outfall pipelines or stormwater drains.

The feed conversion ratio (FCR) is the ratio between the amount of feed actually given to the fish and the resulting fish growth (i.e. the weight of feed used in the farm to produce 1 kg fish) (see Reid *et al.* 2009). The FCR varies between species, and depends on the mass of the fish, the production practises as well as environmental variables such as water temperature (PRDW & Lwandle Technologies 2017). For example, Norwegian Atlantic salmon have a reported FCR of 1.15 (Bjorkli 2002), the FCR of Tasmanian Atlantic salmon is 1.35 (PRDW & Lwandle Technologies 2017), Norwegian Salmon farms show an FCR of 1.16 (Wang *et al.* 2012), and Canada salmon farms have a reported FCR of 1.1 (Strain & Hargraves 2005). The biological FCR for *S. lalandi* and *A. regius* were determined by averaging results reported by Moran *et al.* (2009) and Martelli *et al.* (2013) respectively (Table 2-7). The model will calculate a theoretical food factor based on the species and food data. The FCR for *S. lalandi* is similar to that used by Fernandes & Tanner (2008) in their model.

Sinking speed of faeces (cm/s) for *S. lalandi* and *A. regius* were determined by averaging results reported by Burke (2011) and Martelli *et al.* (2013) respectively.

Table 2-7 Fish data used in the MOM model.

Variable	**Yellowtail (*S. lalandi*)** (Moran *et al.* 2009, Burke 2011)	**Meagre (*A. regius*)** (Martelli *et al.* 2013)
Start weight (g)	40	60
End weight (g)	1 200	1 000
Protein content (0-1)	0.26	0.2
Fat content (0-1)	0.5	0.1
Sinking speed of faeces (cm/s)	0.7	0.7
FCR	2.5	1.4

Table 2-8 Feed data used in the MOM model.

Variable	**Skretting Nova ME**
Protein content (0-1)	0.46
Fat content (0-1)	0.20
Carbohydrate content (0-1)	0.18
Ash content (0-1)	0.09
Sinking speed (cm/s)	8

2.3.7 Biomass and cage layout

As per Stigebrandt *et al.* (2004), it is assumed that the cages of the farm are arranged in R rows (1, 2 or 3) ("standard farm"). Stigebrandt *et al.* (2004) assumes cages are square and of equal size, with side length L and depth D so the horizontal area is L^2 and the cage volume L^2D. However, for non-square pens, L is taken as equal to the square root of the pen area.

The 2011 SEA described design criteria, available fish cage types and the suitable oceanographic conditions for their use (Hutchings *et al.* 2011). Monitoring of the wave climate within Algoa Bay revealed that significant wave heights were less than 2 m for ~90% of the time, suggesting that most types of plastic circle cages will be suitable in the water depth at the proposed ADZs (20-50 m) (Anchor & CapeEAPrac 2013).

Anchor & CapeEAPrac (2013) state that most likely fish cages for commercial finfish outgrowing in the proposed Algoa ADZs would be 70-100 m in circumference (diameter = 20-30 m) and approximately 15 m deep. To prevent build-up of wastes (uneaten food and faeces) below the cages, which would harm the stock, at least 5 m is required below the cage bottom to allow for adequate dispersion. A commercially viable finfish cage farm would require production of approximately 3 000 tons per year (Anchor & CapeEAPrac 2013). However, as a precautionary approach (and in line with recommendations by Anchor & CapeEAPrac 2013), a lower initial scale development will be investigated (maximum 1 000 tons per ADZ). The 'maximum biomass' is the largest biomass allowed in the farm at any one time. Thus, three scenarios are investigated for Algoa 1 and Algoa 7, for various stocking options (Table 2-9).

Table 2-9 Scenarios investigated for Algoa Bay 1 and Algoa 7 sites

Algoa 1								
Scenario	**Maximum biomass (t)**	**Species**	**Number of farms**	**Side length of cages (m)**	**Distance between cages (m)**	**Depth of cages (m)**	**Water depth at farm (m)**	**Reduction factor for through flow**
1	1 000	*S. lalandi* *A. regius*	3	27	10	15	34	0.8
2	3 000	*S. lalandi* *A. regius*	3	27	10	15	34	0.8
Algoa 7								
Scenario	**Maximum biomass (t)**	**Species**	**Number of farms**	**Side length of cages (m)**	**Distance between cages (m)**	**Depth of cages (m)**	**Water depth at farm (m)**	**Reduction factor for through flow**
1	1 000	*S. lalandi* *A. regius*	3	27	10	15	25	0.8
2	3 000	*S. lalandi* *A. regius*	3	27	10	15	25	0.8

2.3.8 Limitations

Hydrodynamic modelling by any known technique is not an exact science. This model presents hypothetical carrying capacity data, but the impacts of the scalability of such a project are unknown. It is strongly recommended implementation occur in a phased approach, with a through monitoring program in place to assess the cumulative impacts. In addition, the economic feasibility of operating farms at the carry capacity indicated is not considered here.

These results do not account for disease control. Alvial *et al.* (2012) recommended a minimum 2.5 km buffers zone be implemented to prevent disease transferral between farms.

2.4 Results

2.4.1 Algoa 1

Modelled results indicate that, for yellowtail (*S. lalandi*) and meagre (*A. regius*), the maximum carbon flux to the sediment is 1 339 g C/sqm/yr and 1 535 g C/sqm/yr respectively (based on 10th percentile current speeds). The relatively high current variability recorded however, suggests there will be sufficient dispersion to ensure 0 g C/sqm/yr carbon flux to the sediment).

Theoretic growth rate (i.e. the time taken to reach end weight) for yellowtail (*S. lalandi*) was 329 days with a theoretical food coefficient of 2.48 (the computed weight of feed required to produce 1 kg of fish) and an energy content of food of 13.7 kJ/kg. Theoretic growth rate of meagre (*A. regius*) was 592 days, with a theoretical food coefficient of 1.25 and an energy content of food of 13.7 kJ/kg.

Maximum biomass production capacity that meets critical ambient conditions (oxygen and ammonia, see Section 2.3.4) over the course of the year is shown in Table 2-10. Total annual production capacity for *S. lalandi* and *A. regius* for Scenario 1 is 3 252 t and 1 637 t respectively (Table 2-10). The limiting factor for growth for both species under all scenarios is oxygen supply to the cages (Table 2-11). The model also indicates that, for Algoa 1, farming *S. lalandi* under all scenarios wastes less food than farming of *A. regius*, but with a higher overall waste production (N and P) (Table 2-11). Assuming that all dissolved nitrogenous waste is in the form of ammonia nitrogen, the predicted, total annual dissolved nitrogen output, when converted into an instantaneous concentration value (based on the volume of the cages and the average current velocity) remains below the ANZECC (2000) WQ guideline of 0.1 $mg.l^{-1}$ for both species under the different scenarios.

These results are in general similar to those reported by Britz & Sauer (2016), although specific outputs are either higher or lower, likely due to updates in the model, and in particular, the inclusion of a species specific component. Attempts were made to reproduce the results using data provided by Britz & Sauer (2016), but results were not comparable due to changes in the software. However, Britz & Sauer (2016) also report that, for Algoa Bay, "*the MOM model indicates that at a projected production of 3 000 t fish per year that there will be efficient dispersal and assimilation of waste from the fish farm due to the high intermittent current speeds*".

As *S. lalandi* farms produce more waste than *A. regius* (as per Table 2-11), the area of impact is larger for yellowtail, and there is therefore a lower carrying capacity for *S. lalandi* than *A. regius*. However, individual *S. lalandi* farms have a higher production capacity over the year than *A. regius* farms (as per Table 2-10).

Table 2-10 Theoretical production capacity (tonnes) for Algoa 1 over an average year.

Scenario	Number of cage rows	Species	Month												Total (t)
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1	1	*S. lalandi*	39.7	329.0	334.3	308.6	291.1	273.7	267.2	252.6	267.2	271.5	298.9	318.6	3252.2
		A. regius	156.4	151.5	153.9	142.1	135.4	126.0	123.0	116.3	123.0	125.0	137.6	146.7	1637.1
2	2	*S. lalandi*	1019.0	986.9	1002.8	925.7	882.3	821.0	801.6	757.9	801.6	814.5	896.5	955.8	10665.5
		A. regius	469.2	454.4	461.8	426.3	406.3	378.1	369.1	349.0	369.1	375.1	412.8	440.1	4911.3

Table 2-11 Theoretical annual waste outlets for total fish production for Algoa 1 (as per total theoretical production, see Table 2-10).

Scenario	Number of cage rows	Species	Number of farms	Limiting factor	Dissolved				To sediment (Particulate Matter)			
					N (kg)	Calculated TAN (mg/l)	Calculated DIN (kg)	P (kg)	N (kgN)	P (kg)	Faeces (kg)	Wasted food (kg)
1	1	*S. lalandi*	2	Oxygen to cages	387 007	0.0001	68 713	65 043	48 782	9 756	1 242 325	9 756
		A. regius	2	Oxygen to cages	85 128	0.00003	15 114	14 733	31 104	4 911	315 956	245 562
2	2	*S. lalandi*	3	Oxygen to cages	1 269 194	0.0004	225 345	213 310	159 982	31 996	4 074 221	31 996
		A. regius	3	Oxygen to cages	255 386	0.00009	45 343	44 201	93 314	14 733	947 877	736 692

2.4.2 Algoa 7

Modelled results indicate that, for yellowtail (*S. lalandi*) and meagre (*A. regius*), the maximum carbon flux to the sediment is 1 100g C/sqm/yr and 1 261g C/sqm/yr respectively (based on 10th percentile current speeds). The relatively strong currents recorded suggest there will be sufficient dispersion to ensure 0 g C/sqm/yr carbon flux to the sediment).

Theoretic growth rate (i.e. the time taken to reach end weight) for yellowtail (*S. lalandi*) was 329 days with a theoretical food coefficient of 2.48 (the computed weight of feed required to produce 1 kg of fish) and an energy content of food of 13.7 kJ/kg. Theoretic growth rate of meagre (*A. regius*) was 592 days, with a theoretical food coefficient of 1.25 and an energy content of food of 13.7 kJ/kg.

Maximum biomass production capacity that meets critical ambient conditions (oxygen and ammonia, see Section 2.3.4) over the course of the year is shown in Table 2-12. Total annual production capacity for *S. lalandi* and *A. regius* for Scenario 1 is 3 252 t and 1 637 t respectively (Table 2-12). The limiting factor for growth for both species under all scenarios is oxygen supply to the cages (Table 2-13). The model also indicates that, for Algoa 7, farming *S. lalandi* under all scenarios wastes less food than farming of *A. regius*, but with a higher overall waste production (N and P) (Table 2-13). Assuming that all dissolved nitrogenous waste is in the form of ammonia nitrogen, the predicted, total annual dissolved nitrogen output, when converted into an instantaneous concentration value (based on the volume of the cages and the average current velocity) remains below the ANZECC (2000) WQ guideline of 0.1 mg.l^{-1} for both species under the different scenarios (Table 2-12).

As *S. lalandi* farms produce more waste than *A. regius* (as per Table 2-13), the area of impact is larger for yellowtail, and there is therefore a lower carrying capacity for *S. lalandi* than *A. regius*. However, individual *S. lalandi* farms have a higher production capacity over the year than *A. regius* farms (as per Table 2-12).

Table 2-12 Theoretical production capacity (tonnes) for Algoa 7 over an average year.

Scenario	Number of cage rows	Species	Month												Total (t)
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1	1	*S. lalandi*	339.7	329.0	334.3	308.6	294.1	273.7	267.2	252.6	267.2	271.5	298.9	318.6	3555.2
		A. regius	156.4	151.9	153.9	142.1	135.4	126.0	123.0	116.3	123.0	125.0	137.6	146.7	1637.3
2	2	*S. lalandi*	1082.0	986.9	1002.8	925.7	882.3	821.0	801.6	757.9	801.6	814.5	896.5	955.8	10728.5
		A. regius	469.2	454.4	461.8	462.3	406.3	378.1	369.1	349.0	369.1	375.02	412.84	440.13	4947.3

Table 2-13 Theoretical waste outlets for total fish production for Algoa 7 (as per total theoretical production, see Table 2-12).

Scenario	Number of cage rows	Species	Number of farms	Limiting factor	Dissolved				To sediment (Particulate Matter)			
					N (kg)	Calculated TAN (mg/l)	Calculated DIN (mg/l)	P (kg)	N (kgN)	P (kg)	Faeces (kg)	Wasted food (kg)
1	1	*S. lalandi*	2	Oxygen to cages	423 068	0.0001	75 115	71 104	53 328	10 665	135 8086	10 666
		A. regius	2	Oxygen to cages	85 139	0.00001	15 116	14 735	31 109	4912	315 999	245 595
2	2	*S. lalandi*	5	Oxygen to cages	1276 691	0.0003	226 676	214 570	160 927	32186	4 098 287	32 186
		A. regius	2	Oxygen to cages	257 259	0.00006	45 676	44 525	93 999	14842	954 829	742 095

3 CONCLUSIONS AND RECOMMENDATIONS

For the Ancylus MOM model, carrying capacity is estimated on the premise that:

1. the benthic fauna beneath the farm site must not be allowed to disappear due to accumulation of organic material;
2. the water quality in the net pens must be kept high; and,
3. the water quality in the areas surrounding the farm must not deteriorate.

As such, Algoa 1 is the ADZ which presents the best opportunity to maximise *S. lalandi* production, while Algoa 7 is the ADZ which presents the best opportunity to maximise *A. regius* production.

Lemley *et al.* (2019) provides figures for annual loads of DIN and DIP entering the coastal waters of Algoa Bay from land based sources as $8.7{\times}10^5$ and $1.4{\times}10^5$ kg, respectively. Furthermore, the authors state that, "anthropogenic nutrient loading to the estuarine and coastal waters of Algoa Bay has facilitated, in part, the increased observations of eutrophic symptoms, including harmful algal blooms (e.g. *Heterosigma akashiwo* and *Lingulodinium polyedra*) and hypoxia (<2mgl^{-1})". These modelled results predict that, for Algoa 1, farming of 1 000 t of *S. lalandi* and *A. regius* produce 68 713 kg DIN and 15 115 kg DIN respectively, while framing of 3 000 t of is predicted to produce 22 5346 kg DIN and 45 344 kg DIN respectively (see Section 2.4.1). A similar pattern is evident for Algoa 7: farming 1 000 t of *S. lalandi* and *A. regius* produce 75 116 kg DIN and 15 117 kg DIN respectively, while farming 3 000 t produces 22 6677 kg DIN and 45 676 kg DIN respectively (see Section 2.4.2). Even considering the worst case scenario, mariculture operations in Algoa Bay at this scale is predicted to input less than 10% of the 870 000 kg DIN currently entering Algoa Bay from land based sources. This does however, constitute a significant cumulative impact of nutrient loading into Algoa Bay that is already regarded as showing eutrophic symptoms due to anthropogenic pollution (Lemley *et al*. 2019).

3.1 Algoa 1

Model results indicate that, for *S. lalandi* and *A. regius*, predicted, total annual dissolved nitrogen output, when converted into an instantaneous concentration value (based on the volume of the cages and the average current velocity) remains below the WQ guideline of 0.1 mg.l^{-1} for both species under the different scenarios. However, it is considered best practise to implement a conservative approach. It is strongly recommended that implementation occur in a phased approach, with a through monitoring program in place to assess the cumulative impacts. Recommend carrying capacity for Algoa 1 is therefore:

- 3 252 t total annual production of *S. lalandi*.
- 4 911 t 12 total annual production of *A. regius*.

These results do not account for disease control. Alvial *et al.* (2012) recommended a minimum 2.5 km buffers zone be implemented to prevent disease transferral between farms. Should this buffer zone be implemented, Algoa 1 has the capacity for one farm of either *S. lalandi*, or *A. regius.*

3.2 Algoa 7

Model results indicate that, for *S. lalandi* and *A. regius*, predicted, total annual dissolved nitrogen output, when converted into an instantaneous concentration value (based on the volume of the cages and the average current velocity) remains below the WQ guideline of 0.1 $mg.l^{-1}$ for both species under the different scenarios. However, it is considered best practise to implement a conservative approach. It is strongly recommended that implementation occur in a phased approach, with a through monitoring program in place to assess the cumulative impacts. Recommend carrying capacity for Algoa 7 is therefore:

- 3 555 t total annual production of *S. lalandi*.
- 4 947 t total annual production of *A. regius*.

These results do not account for disease control. Alvial *et al.* (2012) recommended a minimum 2.5 km buffers zone be implemented to prevent disease transferral between farms. Should this buffer zone be implemented, Algoa 7 has the capacity for one farm of either *S. lalandi*, or *A. regius*.

4 REFERENCES

Anchor Environmental Consultants. 2017. Clark BM, Massie V, Hutchings K, Brown E, Biccard A, Laird M, Harmer R, Makhosonke A, Wright A & Turpie J. 2017. *The State of Saldanha Bay and Langebaan Lagoon 2017, Technical Report*. Report No. AEC 1741/1 prepared by Anchor Environmental Consultants (Pty) Ltd for the Saldanha Bay Water Quality Forum Trust. 87pp.

Anchor Environmental Consultants. 2015. Assessment Framework for the Management of *Effluent from Land-based Sources Discharged to the Marine Environment*. Consulting report for the Department of Environmental Affairs. 87pp.

Anchor Environmental Consultants & CapeEAPrac. 2013. *Draft Marine Specialist Report - Marine aquaculture development zones for finfish cage culture in the Eastern Cape*. Consulting report for the Directorate Sustainable Aquaculture Management: Aquaculture Animal Health and Environmental Interactions, and the Department of Agriculture, Forestry and Fisheries. 54pp.

Alvial A, Kibenge F, Forster J, Burgos J, Ibarra R, St-Hilaire S. 2012. *Recovery of the Chilean salmon industry: The ISA crisis and its consequences and lessons*. Global Aquaculture Alliance - World Bank - SalmonChile, Puerto Montt, Chile. 83 pp.

Australian and New Zealand Environment Conservation Council (ANZECC). 2000. *Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Volume 2, Aquatic Ecosystems*. National Water Quality Management Strategy; no.4. ANZECC, Agriculture and Resource Management Council of Australia and New Zealand, Canberra, Australia.

Black, K.D.E. 2001. *Environmental impacts of aquaculture*. CRC Press, Boca Raton.

Black K.D., McLusky D.S., Nickell T.D., Pereira P.M., Pereira, P.M.F. 2004. Recovery of the sediments after cessation of marine fish farm production. *Aquaculture* 235(1-4): 315-330.

Brooks K.M., Mahnken C., Nash C. 2002. *Environmental effects associated with marine netpen waste with emphasis on salmon farming in the Pacific Northwest*. In: Stickney, R.R. & McVey, J.P. (Eds.). *Responsible Marine Aquaculture*. CAB International, Wallingford, UK.

Burke, A.B. 2011. *The proximate, fatty acid and mineral composition of the muscles of cultured yellowtail (Seriola lalandi) at different anatomical locations*. MSc Thesis, University of Stellenbosch. 44pp.

Carroll, M. L., Cochrane, S., Fieler, R., Velvin, R., White, P. 2003. Organic enrichment of sediments from salmon farming in Norway: environmental factors, management practices, and monitoring techniques. *Aquaculture* 226(1-4): 165-180.

Cromey, C.J., Nickell, T.D., Black, K.D., 2002. DEPOMOD—modelling the deposition and biological effects of waste solids from marine cage farms. *Aquaculture* 214: 211 – 239.

Cromey, C.J., Black, K.D., Edwards, A., Jack, I.A. 1998. Modelling the deposition and biological effects of organic carbon from marine sewage discharges. *Estuarine, Coastal and Shelf Science* 47: 295– 308.

Davenport, J., Black, K., Burnell, G., Cross, T., Culloty, S., Ekarante, S., Furness, B., Mulcahy, M. & Thetmeyer, H. 2003. *Aquaculture: the ecological issues*. Blackwell Publishing, Oxford.

Department of Water Affairs & Forestry (DWAF). 1995. *South African Water Quality Guidelines for Coastal Marine Waters. Volume 1 - Natural Environment*. Pretoria.

Dumbauld, B.R., Ruesink, J.L., Rumrill, S.S., 2009. *The ecological role of bivalve shellfish aquaculture in the estuarine environment: a review with application to oyster and clam culture in West Coast (USA) estuaries*. Aquaculture 290: 196–223.

Ervik, A., Hansen, P.K., Aure, J., Stigebrandt, A., Johannessen, P., Jahnsen, T. 1997. Regulating the local environmental impact of intensive marine fish farming: I. The concept of the MOM system (Modelling–Ongrowing fish farms– Monitoring). *Aquaculture* 158: 85– 94.

Food and Agriculture Organization of the United Nations (FAO) 2018. *The State of World Fisheries and Aquaculture 2018 - Meeting the sustainable development goals*. Rome. Licence: CC BY-NC-SA 3.0 IGO

Felsing, M., Glencross B., Telfer T., Felsing, B. 2005. Preliminary study on the effects of exclusion of wild fauna from aquaculture cages in a shallow marine environment. *Aquaculture* 243: 159-174.

Fernandes, M. & Tanner, J. 2008. Modelling of nitrogen loads from the farming of yellowtail kingfish *Seriola lalandi* (Valenciennes, 1833). *Aquaculture Research* 39: 1328-1338.

Findlay, R.H. & Watling, L. 1997. Prediction of benthic impact for salmon net-pens based on the balance of benthic oxygen supply and demand. *Marine Ecology Progress Series* 155: 147–157.

Gowen, R.J., & Ezzi, I.A. 1992. *Assessment and production of the potential for hypernutrification* and eutrophication associated with cage culture of salmonids in Scottish coastal waters. Dunstaffnage Marine Laboratory, Oban

Gowen, R., Brown, J., Bradbury, N., McLusky, D.S. 1988. *Investigations into benthic enrichment, hypernutrification and eutrophication associated with mariculture in Scottish coastal waters*. Report, University of Stirling, UK. 289 pp.

Hansen, P.K., Ervik, A., Schaanning, M., Johannessen, P., Aure, J., Jahnsen, T., Stigebrandt, A., 2001. Regulating the local environmental impact of intensive, marine fish farming: II. The monitoring programme of the MOM system (Modelling– Ongrowing fish farms – Monitoring). *Aquaculture* 194: 75– 92.

Hevia, M., Rosenthal, H., Gowen, R.J. 1996. Modelling benthic deposition under fish cages. *Journal of Applied Ichthyology* 12:71– 74.

Holmer, M., Wildish, D.J., and Hargrave, B. 2005. *Organic enrichment from marine finfish aquaculture and effects on sediment biogeochemical processes*. *In* The handbook of environmental chemistry, Vol 5M. Water pollution. *Edited by* B.T. Hargrave. Springer-Verlag, Berlin: 181-206.

Jooste, J. G. 2009. *The Identification of Sea Based Sites Suitable For Marine Aquaculture Development Zones in South Africa*. Report prepared for Marine and Coastal Management, Department Of Environmental Affairs And Tourism.

Kishi, M.J., Uchiyama, M., Iwata, Y. 1994. Numerical simulation model for quantitative management of aquaculture. *Ecological Modelling* 72: 21– 40.

Lemley, D.A., Adams, J.B., Bornman, T.G., Campbell, E.E., Deyzel, S.H. 2019. Land-derived inorganic nutrient loading to coastal waters and potential implications for nearshore plankton dynamics. *Continental Shelf Research*.

Martelli, R., Parisi, G., Lupi, P., Bonelli, A., Zotte, A. D., Franci, O. 2013. Effect of rearing system on body traits and fillet quality of meagre (*Argyrosomus regius*, Asso 1801) chilled for a short time. *Italian Journal of Animal Science* 12(2): e30.

McDonald, M.E., Tikkanen, C.A., Axler, R.P., Larsen, C.P., Host, G. 1996. Fish simulation culture model (FISC): a bioenergetics-based model for aquaculture waste load application. *Aquacultural Engineering* 15: 243–259.

Moran, D., Pether, S.J., Lee, P.S. 2009. Growth, feed conversion and faecal discharge of yellowtail kingfish (*Seriola lalandi*) fed three commercial diets. *New Zealand Journal of Marine and Freshwater Research* 43: 917-927.

National Research Council. 2010. *Ecosystem Concepts for Sustainable Bivalve Mariculture*. Washington, DC: The National Academies Press. https://doi.org/10.17226/12802.

Navarro, N. 2000. *Planktonic ecosystem impacts of salmon cage aquaculture in a Scottish sea loch*. ICES Cooperative Research Report 240, Denmark. [Online]: http://www.ices.dk/sites/pub/Publication%20Reports/Cooperative%20Research%20Report%20(CRR)/crr263/CRR263.pdf (accessed 2018-11-07).

Panchang, V., Cheng, G., Newell, C. 1997. Modelling hydrodynamics and aquaculture waste transport in coastal Maine. *Estuaries* 20: 14– 41.

Pitta, P., Apostolaki, E. T., Giannoulaki, M., Karakassis, I. 2005. Mesoscale changes in the water column in response to fish farming zones in three coastal areas in the Eastern Mediterranean Sea. *Estuarine, Coastal and Shelf Science* 65(3): 501-512.

Porrello, S., Tomassetti, P., Manzueto, L., Finoia, M. G., Persia, E., Mercatali, I., Stipa, P. 2005. The influence of marine cages on the sediment chemistry in the Western Mediterranean Sea. *Aquaculture* 249(1-4): 145-158.

Rosenthal, H. 2001. MARAQUA. The Derivation of Scientific Guidelines for the Best Environmental Practice for the Monitoring and Regulation of Marine Aquaculture in Europe. *Journal of Applied Ichthyology* 17: 145– 206.

Ruiz, J.M. 2001. Effects of fish farm loadings on seagrass (*Posidonia oceanica*) distribution, growth and photosynthesis. *Marine Pollution Bulletin* 42(9): 749-760.

Sarà, G., Scilipoti, D., Mazzola, A., Modica, A. 2004. Effects of fish farming waste to sedimentary and particulate organic matter in a southern Mediterranean area (Gulf of Castellammare, Sicily): a multiple stable isotope study (δ13C and δ15N). *Aquaculture* 234(1-4): 199-213.

Schumann, E.H. 1998. Wind-driven mixed layer and coastal upwelling processes off the south coast of South Africa. *Journal of Marine Research* 57: 671-691.

Silvert, W. 1992. Assessing environmental impacts of finfish aquaculture in marine waters. *Aquaculture* 107: 67–79.

Shumway, S.E. & R.B. Whitlatch. 2011. *Biofouling in marine molluscan shellfish aquaculture: A survey assessing the business and economic implications of mitigation*. Journal of the World Aquaculture Society 42(2): 242-252.

Staniford, D. 2002a. A *big fish in a small pond: the global environmental and public health threat of sea cage fish farming*. Sustainability of the Salmon Industry in Chile and the World Workshop organized by the Terram Foundation and Universidad de los Lagos in Puerto Montt, Chile.

Staniford, D. 2002b. *Sea cage fish farming: an evaluation of environmental and public health aspects (the five fundamental flaws of sea cage fish farming).* Unpublished paper presented to the European parliament's Committee on Fisheries Public hearing on 'Aquaculture in the European Union: present situation.

Stigebrandt, A., 1999. *Turnover of energy and matter by fish—a general model with application to salmon*. Fisken and Havet No. 5, Institute of Marine Research, Norway. 26pp.

Stigebrandt, A. 1986. *Model computations of the environmental load caused by fish farms*. NIVA Report No. 1823.28 pp.

Stigebrandt, A., Aure, J., Ervik, A., Hansen, P. K. 2004. Regulating the local environmental impact of intensive marine fish farming: III. A model for estimation of the holding capacity in the Modelling–Ongrowing fish farm–Monitoring system. *Aquaculture* 234(1-4): 239-261.

Stigebrandt, A. & Aure, J. 1995. *A model for critical loads beneath fish farms*. Fisken and Havet No. 26, Institute of Marine Research, Norway, 1 – 27 + Appendix 1. 27 pp.

Vita R., Marin A., Madrid J.A., Jimenez-Brinquis B., Cesar A, Marin-Guirao, L. 2004. Effects of wild fishes on waste exportation from a Mediterranean fish farm. *Marine Ecology Progress Series* 277: 253-261.

agriculture,
forestry & fisheries

Department:
Agriculture, Forestry and Fisheries
REPUBLIC OF SOUTH AFRICA

ANCHOR
research & monitoring