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Strengthening and supporting further development of aquaculture in the Kingdom of Saudi Arabia
PROJECT UTF/SAU/048/SAU

Guidelines and Criteria

on Technical and Environmental Aspects of Cage Aquaculture Site Selection in the Kingdom of Saudi Arabia

Cover photograph:
A marine finfish cage farm using floating HDPE cages
(courtesy Alessandro Ciattaglia)

GUIDELINES AND CRITERIA

ON TECHNICAL AND ENVIRONMENTAL ASPECTS OF CAGE AQUACULTURE SITE SELECTION IN THE KINGDOM OF SAUDI ARABIA

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PREPARATION OF THIS DOCUMENT

These technical guidelines and criteria were prepared by the consultants Alessandro Ciattaglia (Cage Culture Expert) and Richard Anthony Corner (Environmental Expert), commissioned by FAO in the framework of the Project UTF/SAU/048/SAU "Strengthening and supporting further development of aquaculture in the Kingdom of Saudi Arabia".

The consultants' terms of references (TORs) for this was to draft technical guidelines and devise criteria (where appropriate) for the development of offshore cage aquaculture on the Red Sea coast, with special reference to site selection. The guidelines and criteria cover both technical aspects related to necessary cage and mooring design and the environment aspects that affect such design and environmental criteria as they affect the fish in the cages and more generally as they affect the long-term sustainability of fish farm aquaculture within the Kingdom of Saudi Arabia.

Alessandro Ciattaglia and Richard Anthony Corner

ACRONYMS AND ABBREVIATIONS

ADMA	Aquaculture Department of the Ministry of Agriculture
AF	Antifouling
CAFP	Cage Aquaculture Feasibility Project
FAO	Food and Agriculture Organization
HDPE	High Density Polyethylene
Hs	Significant Wave Height
KSA	Kingdom of Saudi Arabia
MoA	Ministry of Agriculture
NNW	North-North West
NNE	North-North East
PE	Polyethylene
PE100	Polyethylene Density 100
PME	Presidency Meterology and Environment
PN10	Nominal Pressure 10 bar

1. General Introduction

Aquaculture and more specifically marine aquaculture is a growing industry that currently supplies approximately 50 percent of the world's global fish market. This will certainly continue with an anticipated global increase in production of 30 million tonnes required by 2050 to provide fish products to a growing population globally. FAO indicates that Mariculture, growing fish in the sea, will be the major sub-sector of this industry to expand in to the future. The marine environment offers an available resource and provides space for expansion, even recognising competing needs.

The Kingdom of Saudi Arabia has two coastlines, in the west the Red Sea and in the East the Arabian Sea. The KSA is expected to expand Mariculture primarily in the Red Sea and it is on this premise that these guidelines and (where relevant and available) criteria have been developed. Much of the detail, however, is generally applicable and may equally apply to all KSA coasts.

Expansion and long-term sustainability of the aquaculture in the Red Sea will depend on the development and adoption of best management practices, which includes identification and selection of the right sites in which to locate fish farms, the subject of this document.

Any aquaculture project has, among its early primary tasks, the selection of the most suitable site for the farming business. An error in the site selection and evaluation stage can strongly influence the profitability, impact running costs and production capacity and affect fish mortality, health and welfare, which combined would make any fish farm unsustainable in the long-term.

The selection of a marine site or zone that would be suitable for deploying the physical infrastructure necessary to grow fish and then growing the fish in cages requires a number of technical and environmental considerations, prior to the site being selected and operations begun. This document provides the user with some guidelines and criteria for consideration in the selection of suitable sites within the Kingdom of Saudi Arabia (KSA). It should be noted that decisions over siting are often complex and require interpretation. For example a site with good water flow will remove wastes and replace oxygen in the cages, but the site will remain unsuitable if it is too shallow. Conversely a deep site is useful, but not if the water flow is very low. Thus when reading this document consideration must be given to combined factors in determining what a very good site is and what is not, and many sites will fall between these two extremes.

Attempts have been made to ensure that any guidelines and criteria given comply with the regulations in force within KSA. The aquaculture regulations issued through the Department of Aquaculture at the Ministry of Agriculture and other Environmental laws and Regulation issued through and administered by the Presidency Meteorology and Environment (PME) should take precedence when any errors or inconsistencies are identified.

Please note also that these guidelines and criteria do not specifically refer to the aquaculture application and licensing process, and the reader should refer to these procedures specifically. In general this is a guide to help support good site selection, with details on environmental choices that affect the fish being grown and the infrastructure needed to grow the fish, environmental considerations of long term sustainability and other factors that will affect the choices made.

2. Siting Defined

The siting of a cage aquaculture facility in the marine environment is a process of selecting an appropriate location in which to place fish cages, moorings and other necessary infrastructure. Even where an area has been allocated (e.g. an aquaculture zone allocated to an individual or company, based for example on selection using GIS), there is still a need to consider locations within the zone that are appropriate for cage aquaculture.

Deciding on a particular site requires a set of information, and consideration of that information, to be able to make an informed decision. Siting requires consideration of inshore and offshore locations and the impacts that the environment has on that decision, in terms of the technology to be used, environmental considerations on the choice of technology, environmental impacts on the surrounding area, environmental considerations as it affects the fish stock, and consideration of other users to avoid conflicts. The marine environment is a resource that must be assessed to ensure the siting of the cages and infrastructure has a long-term sustainable future. In this way good siting of cage culture in the marine environment is critical to the long term success of the operation, will enable the fish farm company to grow fish successfully and have the smallest possible impact on the environment.

2.1 Inshore / Offshore

Marine locations are generally divided by two simple discriminant descriptors, inshore and offshore, based on the generic consideration of exposure to bad sea weather conditions and in particular whether or not the site is subject to oceanic waves (offshore) or not (inshore).

Within these generic descriptors there are numerous classifications which are still debated without generating any common definitions. This inability to define inshore and offshore results from the variable conditions that any specific country encounters that does not lend itself to a specific description. Tables 1 to 4 list some classifications from different sources.

In the table below (Table 1) is a classification proposed by FAO in 2009 as part of their study into offshore cage aquaculture.

TABLE 1: SITE CLASSIFICATION PROPOSED BY FAO IN 2009 (EXPERT WORKSHOP ON OFFSHORE CAGE AQUACULTURE)

	Coastal	Off the Coast	Off Shore
Location/ hydrography	than 500m from the> coast • 10m depth at ≥ ;low tide • Within sight • Usually sheltered •	,500m - 3km • 10m <depth at low tide ≤ 50 ;m • Often within sight • Somewhat sheltered •	2+km, generally within continental shelf zones, possibly open-ocean • 50m depth < •
Environment	,Hs usually < 1m • Short period ,winds • Localized coastal currents, possibly strong tidal streams •	Hs <= 3 - 4m • Localized coastal currents, some tidal streams •	Hs 5m or more, regularly ,2- 3m • ,oceanic swells • ,variable wind periods • possibly less localized current effect •
Access	accessible 100% • Landing possible at all times •	accessible on at least 90%< ,once daily basis • Landing usually possible •	,Usually > 80% accessible • landing may be possible, periodically, e.g. every 3 - 10 days •
Operation	Regular, manual involvement, feeding, monitoring, etc •	Some automated operations, e.g. feeding, monitoring, etc •	,Remote operations • ,Automated feeding • Distance monitoring, system function •

Another possible classification is provided by the Norwegian site classification NS9415 – edition1 (Table2), which is based on Significant Wave Height (Hs) measurements and degrees of exposure; or as an alternative (Table 3) based on current speed. The sites are ranked from A to E where A refers to sheltered sites inshore site while E refers to very exposed, offshore sites.

TABLE 2: NS9415 - NORWEGIAN SITE CLASSIFICATION BY HS DIMENSION AND PERIOD

Site Class	Significant Wave Height - Hs [m] (Hs)(Meters)	Period [s]	Degree of Exposure
A	0.5>	2.0 >	Small
B	1.0 - 0.5	3.2 – 1.6	Moderate
C	2.0 - 1.0	5.1 – 2.5	Medium
D	3.0 - 2.0	6.7 – 4.0	High
E	3.0<	18.0 – 5.3	Extreme

TABLE 3: NS9415 - NORWEGIAN SITE CLASSIFICATION BY CURRENT SPEED

Site Class	Current speed [m/s] (Hs)(Meters)	Degree of Exposure
A	0.3>	Small
B	0.5 - 0.3	Moderate
C	1.0 - 1.5	Medium
D	1.5 – 1.0	High
E	1.5<	Extreme

Alternatively inshore and offshore can be described on consideration the Risk Factors generated by different parameters related to both the environment and the farming production practice and infrastructure requirements (Table 4, R. Turner, Seawork Scotland Ltd, Pers. Com.).In this instance parameters are ranked from 0 to 5 (being low risk >high risk). Note that Table 4 does not give a definition for KSA, but the table could be used to evaluate the relative risks associated with each site (based on distance to shore).

TABLE 4: LOCATION CRITERIA AND RISK FACTORS TO IDENTIFY INSHORE AND OFFSHORE SITES.

Location	Sheltered Site - In-shore	Semi-Offshore Site	Offshore Site
Investments	low	Medium	High
Distance from the Shore	m – 200 m 50	0.5km – 2 km	2km – 20 km
Significant High Wave (Hs) during storming weather	2m>	3m – 9m	9m<
Hs probability of 60% of days per year	0.6m>	1.5m>	2.5m>
Site Depth	5m – 15m	15m – 50m	50m<
Risk Factor related to the Fish Farming procedure			
Diseases	4	2	1
Predators	3	2	1
Algal bloom	5	3	1
Pollution of the water	5	2	0
Low growth factor	4	2	2
Equipment cost	1	3	5
Operational cost	1	4	5
Storming weather damage on the equipment	2	4	5
Wear and Tear	1	5	5
Safety and Vandalism	2	3	4
Work safety	1	3	5
Risk Factor related to the Marine Environment			
Anoxic seabed	5	3	1
Fish Escapes	3	2	1
Shipping Interference	4	2	1
Visual Impact	5	2	0
Other Risks			
Market price drop	2	3	5
Over-production	1	3	4
Consumer healthy food	3	2	1
AVARAGE TOTAL RANK	**2.88**	**2.77**	**2.61**

In the KSA, the distinction between inshore and offshore aquaculture, is more likely to reflect the point at which a site is no longer protected from any form of reef system and therefore subject to oceanic waves. The physical distance from the shore for the distinction between in inshore and offshore waters will therefore vary along the KSA coast.

In the KSA it is highly likely that aquaculture will develop inside or very close to the reef area which provide suitable water depths, and should therefore be considered inshore activity. GIS analysis of suitable areas for aquaculture development will need to be carried out in order to determine general site availability, in both inshore and offshore areas.

2.2 Environmental and other considerations in site selection

Sections 3 – 6 provide more detailed guidelines and criteria on the environmental, technical and other considerations needed in siting cages in the marine environment. As a general introduction the selection of a site encompasses consideration of detailed parameters within 4 main categories (in no specific order):

a. Environmental criteria related to the biology of the farmed fish;

b. Environmental criteria related to the cages and mooring design;

c. Environmental criteria related to the environmental sustainability;

d. Legal, logistics and infrastructure.

And in summary requires consideration of the following key components within each category:

a. Environmental criteria related to the biology of the farmed fish

- Water Temperature
- Salinity
- Current
- Water exchange/Dissolved Oxygen
- Water depth/Bathymetry
- Suspended Solids
- Pollution
- Fouling
- Algal Blooms
- Existence of disease
- Existence of other aquaculture activity
- Rivers/water effluents/Wadis

b. Environmental criteria related to the cages and mooring design

- Bathymetry
- Max wave height, direction and period
- Main current speed and direction
- Max Tidal height
- Main wind speed and direction
- Fouling
- Sea bed morphology

c. Environmental criteria related to the environmental sustainability

- Sea bed composition
- Benthic community
- Water speed and direction
- Nutrient deposition
- Fragile ecosystems
- FAD (Fish Aggregating Device) phenomenon

d. Other considerations in siting aquaculture facilities in the marine environment

- Military protected areas
- Special restricted area
- Regulated Navigation area
- Marine Nature Reserves
- Distance from the shore
- Distance from the farm land facilities
- Roads access
- Electricity and potable water supply services
- Proximity to harbor/jetty/marina
- Proximity to the market
- Proximity to main airport
- Fisheries communities
- Touristic areas

Guidelines, and where appropriate criteria, for each of the components is provided in the following sections.

3. Environmental criteria related to the biology of the farmed fish

This section deals with a consideration of the selected fish species and of the environmental criteria that will affect the performance of stock during the culture cycle, and is therefore relevant to consider at the point of site selection. There is no specific guidance on the choice of fish species to be grown in a specific site. However, there are two general recommendations that are applicable, namely:

a) Species should be selected from native stocks of fishes, if at all possible.

b) Translocation of species should be avoided, if at all possible.

Choice of species will depend on whether or not they have been cultured before, so that that there is experience available and whether or not the full cycle of production (fertilization, egg production and hatchery stages and on-growing in cages) is fully understood.

Ignoring any specific difficulties in culture, native species (e.g. Yellowtail Kingfish or *Seriola lalandi*) provide ideal candidates for aquaculture because there will already be a readiness in the market to accept the fish at sale; living in the wild the native fish will already be acclimatized to growing under the same environmental conditions it will experience in culture; and should fish escape during production, the native species is less likely to have a negative impact on other fish stocks.

It is recognized that translocation of fish will be required, however, until such time as the KSA has sufficient hatchery infrastructure available and is able to supply sufficient fry-stock internally. Within KSA current candidate species include Barramundi (*Lates calcarifer*) and Sea Bream (*Sparus aurata*). Both are translocated species, but having been produced within KSA for up to 20 years are considered native in the context of aquaculture development.

Having made the choice of species there are a number of considerations that need to be made in selecting a site. These are discussed below. It should be noted that specific parameters are often affected by one or more of the associated parameters discussed, such as sea temperature affecting oxygen solubility. Attempts have been made to identify these, when this is the case.

3.1. Water Temperature

Water temperatures in the Red Sea vary from north to south, and seasonally resulting primarily from the two distinct monsoon periods. The average sea surface temperature is approximately 26°C in the north and 30°C in the south during the summer months, and being approx. 2 - 3°C lower in winter (Figure 1).

High water temperatures affect fish by:

1) Increasing the fishes biological processes, which increase demand for oxygen from the water column;

2) Reducing the solubility of oxygen in the water column reducing the quantity available for the fish; and

3) This happens at a time when oxygen concentration is suppressed due to the high temperatures (See 3.3).

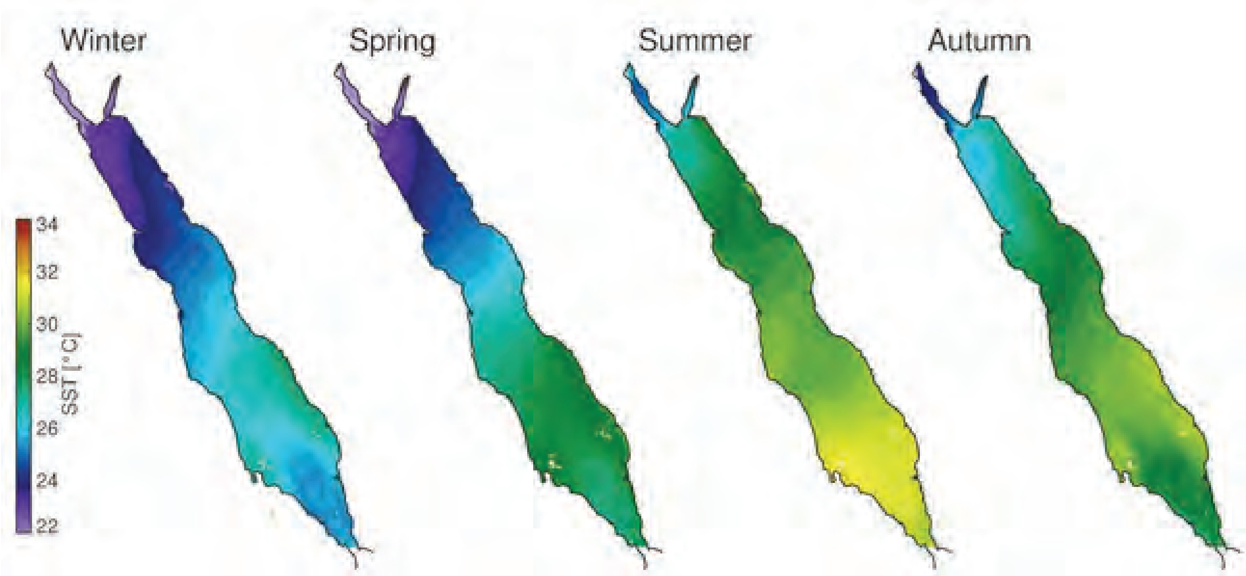

FIGURE 1: SEASONAL CHANGES IN TEMPERATURE WITHIN THE RED SEA OVER THE PERIOD 2003 – 2011 AS RECORDED BY MODIS[1].

Fish are generally flexible in their temperature range, having an optimum temperature range (rather than single temperature) for growth and survival (Figure 2). Outside this range (either higher or lower) fish will undergo stress (poor growth, susceptibility to disease) and further still, at the incipient lethal level, will die.

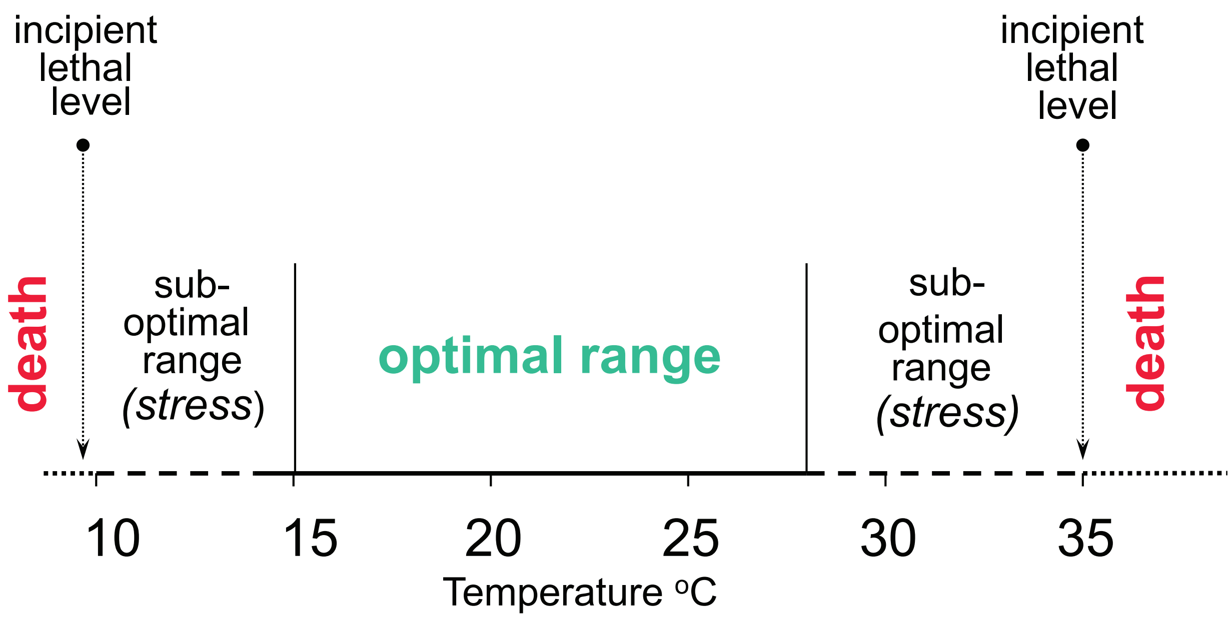

FIGURE 2: GENERAL SCHEME OF OPTIMAL, STRESSFUL AND LETHAL TEMPERATURE RANGE IN FISH.

[1] Raitsos et al 2013 available at DOI: 10.1371/journal.pone.0064909 1 •

Optimal temperatures for fish species likely to be grown in the KSA are:

1) Kingfish (*Seriola* sp) 18 – 24°C

2) Barramundi (*Lates* sp.) 26 - 28°C

3) Bream (*Sparus* sp.) 14 - 22°C

Though it should be noted that fish will grow and develop outside of these temperature ranges, perhaps less efficiently than in optimum temperatures. Thus is likely, based on temperature alone, that Barramundi is a candidate to be grown in the south of the Red Sea and Bream and Kingfish grown in the north. Lethal limits for these fish are significantly above and below the temperatures noted, at temperatures that are unlikely to be recorded in the Red Sea.

3.2 pH

The pH of water is a measure of the concentration of hydrogen ions in the water:

$pH = - \log [H^+]$

Note that because it is a logarithmic scale a change in pH of one unit is equivalent to a 10 fold-change in hydrogen ion concentration. pH is defined on a scale of 1 to 14; a pH < 7 is acid and a pH > 7 is alkaline.

The pH of the marine system will vary slightly day to day, but is generally between 7 and 9, which provide ideal growing conditions for fish species (Figure 3). Outside of this range fish will be affected by sub-lethal effects, such as skin and gill damage, and poor growth. Although ocean acidification is a long term issue it is unlikely that pH will change sufficiently to affect aquaculture in the Red Sea in the short-medium term as a result of global acidification.

pH is not a primary site selection component, except when the site might be affected by outflows from desalination plants. Effects are liable to be local and changes in seawater pH which can result from wastewater which can contain chemicals used in flocculation, anti-scaling additives and acids used to alter pH during the desalination process, which may then enter the marine environment, lowering overall pH. Studies have shown that the extent of the pH changes, relatively, is small and not likely to affect fish growing.

However, it is recommended that fish farming not be allowed to take place within an exclusion zone around a desalination plant. The extent of an exclusion zone around a desalination plant for aquaculture has not been researched and no literature exists. As a precautionary measure it is thought that the exclusion zone for aquaculture sites should be a minimum of 3km from the desalination plant, in all seaward directions.

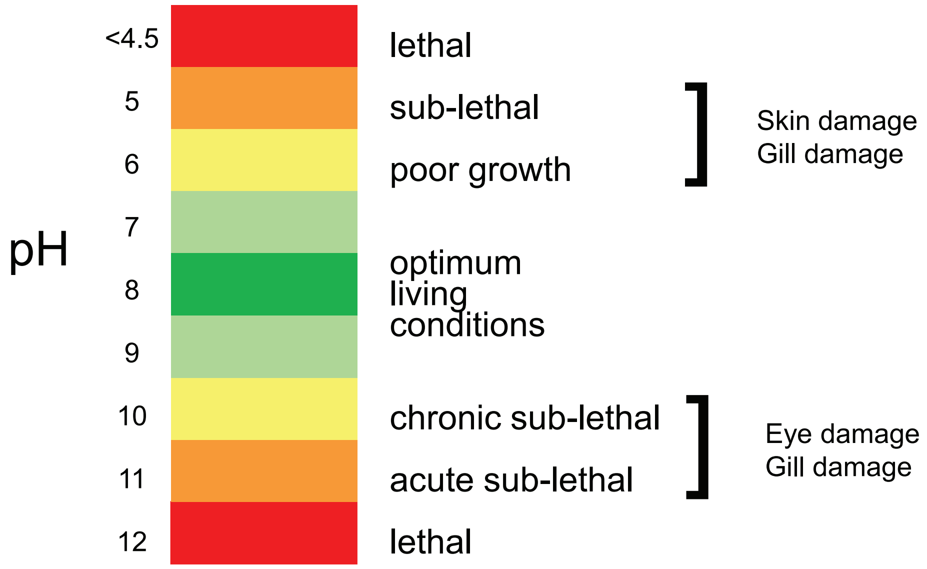

FIGURE 3: PH SCALE

3.3. Dissolved Oxygen concentration

There are three main physical factors affecting the amount of oxygen water can hold (*i.e.* the solubility of oxygen in water); these are:

- ***Temperature***, where water holds less oxygen at higher temperatures;
- ***Salinity*** where water holds less oxygen at higher salinities; and
- ***Pressure*** where water holds less oxygen at low atmospheric pressures (e.g. at high altitude) – and can be ignored here.

Table 5 shows how the solubility of oxygen in seawater (freshwater added as a reference only) reduces at higher temperatures and salinities, as will be experienced by fish grown in the Red Sea.

Under standard environmental conditions (no fish farming activity) oxygen concentration in seawater at the proposed site should be at the temperature/salinity norm (as defined in Table 5).

Once the fish farm has started, farm operations should affect oxygen concentration only over short durations and only within and very close to the cages. Fish bio-processing of feed in the gut uses oxygen from the water, which can reduce the water oxygen concentration within the cages. To prevent disease and increase the fish welfare, oxygen concentration should not fall below 60% of normal levels for extended periods. If the current speed is sufficient (see 3.5) then low oxygen within the cage will be replaced relatively quickly after feeding has stopped.

TABLE 5: CONCENTRATION OF OXYGEN[2] (MG/L) IN SEAWATER AT 40PPT (RED SEA AVERAGE SALINITY), 35PPT (GLOBAL SEA AVERAGE SALINITY) AND IN FRESHWATER (REFERENCE) OVER TEMPERATURE RANGE 20 TO 35°C AT STANDARD ATMOSPHERIC PRESSURE (1BAR) ASSUMING 100% SATURATION. VALUES TO 2 DECIMAL PLACES.

Water Temp °C	Solubity of oxygen at salinity of 40ppt	Solubity of oxygen at Std salinity of 35ppt	Solubility of oxygen in freshwater (0ppt)
20	**7.18**	7.40	9.09
21	**7.05**	7.26	8.92
22	**6.93**	7.13	8.74
23	**6.81**	7.01	8.58
24	**6.69**	6.89	8.42
25	**6.58**	6.77	8.26
26	**6.47**	6.66	8.11
27	**6.37**	6.55	7.97
28	**6.26**	6.44	7.83
29	**6.16**	6.34	7.69
30	**6.07**	6.24	7.56
31	**5.97**	6.14	7.43
32	**5.88**	6.04	7.31
33	**5.79**	5.95	7.18
34	**5.70**	5.86	7.07
35	**5.62**	5.77	6.95

If any treatments of the fish are required, fish might be needed to be crowded within a smaller space (e.g. net lifted), then oxygenation of the water is recommended during the treatment process.

[2] Oxygen solubility calculator http://www.baldr.biz/reference/solubility-of-oxygen-in-seawater-online-calculator

Other biological/environmental factors that influence the amount of dissolved oxygen in water include:

Phytoplankton blooms

During blooms periods dissolved oxygen will fluctuate during the day due to photosynthetic activity by the algae (which produces oxygen), with maximum concentrations during late afternoon. Algae also take up oxygen overnight, however, when sunlight for photosynthesis is not available and thus minimum concentrations tend to occur at dawn. Dissolved oxygen will also decrease during the death of blooms due to the increased respiration of bacteria, which will act to break down the decaying bloom.

Organic loadings

Bacterial oxidation of organic matter removes oxygen from water, so if you have high loading in the water column this reduces oxygen concentration in the water.

Respiration

Of the fish but also other aquatic vertebrates and invertebrates, all acting to remove dissolved oxygen from the water column and sediments.

The basic requirement of fish for dissolved oxygen varies considerably, depending on:

Species:

Oxygen requirements vary massively between species (some representative requirement figures are shown in the handout);

Size:

Fry and juvenile fish normally require proportionately more oxygen per unit weight than adult fish;

Activity:

Exercising fish require more oxygen than resting fish; resting fish require sufficient to cover basic metabolic functions. Active fish require the additional oxygen to feed muscular activity, increased heart rate and other functions associated with activity (e.g. swimming).

Temperature:

Fish normally require more oxygen as temperature increases, simply because as the temperature increases the rate at which minimum metabolic function occurs also increases with this increased temperature. This occurs at a time when water holds less oxygen because of the higher temperatures.

Feeding:

Oxygen requirements increases after feeding because oxygen is required to digest the food through Specific Dynamic Action (SDA), the SDA being the amount of energy required to process (break down) feed into its constituent parts for absorption.

Stress:

Stressed fish require more oxygen (this may cause problems if fish are stressed at times of low oxygen or poor water quality).

Typical oxygen requirements vary with species but generally range from:

- *Resting fish:* 100 - 500 mg DO kg wet weight^{-1} h^{-1}
- *Active fish:* 300 - 1500 mg DO kg wet weight^{-1} h^{-1}

The first indication of possible oxygen stress may be a change in fish behaviour, with fish crowding at the surface gasping for air (oxygen). If sustained over a period of time, low dissolved oxygen may result in significant sub-lethal (certainly acute and perhaps long-term chronic problems) and potentially direct lethal effects.

3.4. Salinity

Salinity in the Red Sea ranges from approximately 36 ‰ in the southern part to approximately 41 ‰ in the north, which an overall average of 40 ‰, higher than average global salinity due to high evaporation and low rainfall runoff, lower in the south by virtue of the limited connection to the Gulf of Aden through the Bab-el-Mandeb strait.

Salinity is one of the variables affecting dissolved oxygen concentration in the water column (See 3.3 above).

Salinity tolerance of fish species is variable. Fish that are native to the Red Sea will happily tolerate the elevated salinities, translocated species will adjust (acclimatize) relatively quickly, depending on the salinity they are from.

Of the three species identified as aquaculture candidates, the Gilthead Sea Bream (*Sparus aurata*) and Barramundi (*Lates calcarifer*) are Euryhaline fish and are able to tolerate a wide range of salinities (2 – 60 $^{o}/_{oo}$), whereas Yellowtail Kingfish tolerate salinities ranging from brackish to full seawater (approx. 18 – 50 $^{o}/_{oo}$), and so should not require any acclimatization to conditions within the Red Sea.

One point of note, as it relates to aquaculture site selection, is that desalination plants can increase salinity by 5 – 10 points locally. Although this is within the ranges proposed above, it should be noted that the increase in salinity reduces the ability of seawater to retain oxygen and oxygen concentration in local waters around desalination plants may drop below reasonable levels for cultivation.

3.4. Water Depth / Bathymetry

Over and above infrastructural limitations on depth (see Section 4) there are several biologically good reasons to have sufficient water depth at a cage site.

1) Having a site that is too shallow will limit the dispersion of farm waste materials away from the farm, leading to a build-up of waste materials on the seabed directly beneath cages (See section 5.1);

2) If re-suspension of deposited materials occurs at shallow sites then this can enter the cage. Breakdown processes will increase bacterial oxygen consumption within the cage, suspended materials reduce visibility, may induce stress in the fish and they will respire more quickly and reduce the oxygen concentration in the cage, and floating particulates may cause an irritant to fish gills which will reduce the ability to process oxygen and may also lead to increased susceptibility to disease and to secondary infection of the gill lamellae;

3) Fish in cages, in general, naturally swim in the same direction, which can create a mild vortex within the cage during periods of low current speed (quiescent water) and result in the suction of water up through the bottom of the cage from below the cages. This may increase the ingress of re-suspended material into the cages, in the event of re-suspension of waste materials;

4) In extreme cases, very high deposition of waste materials into sediments may result in the production of decomposition process gases that affect fish stocks (see section 5.2);

5) Good water depth aids flushing the site with fresh clean water, renewing oxygen in the cages and maintaining water flow to maintain fish health.

6) However, it should be noted that deep sites, with good currents, are often more exposed which carries additional costs associated with infrastructure, but also in a likely increase in feed use and slower growth in fish stock.

3.5. Suspended Solids

Suspended materials in the water column can come from three sources:

1) Primary and secondary productivity;

2) Faecal matter in suspension; and

3) Re-suspension of wastes from the seabed.

The Red Sea is oligotrophic, and as such natural primary productivity will be low in the Red Sea with Chlorophyll-a concentrations something less than 1µg/l (Figure 4) during the majority of the year, lower in the north, compared to the southern Red Sea.

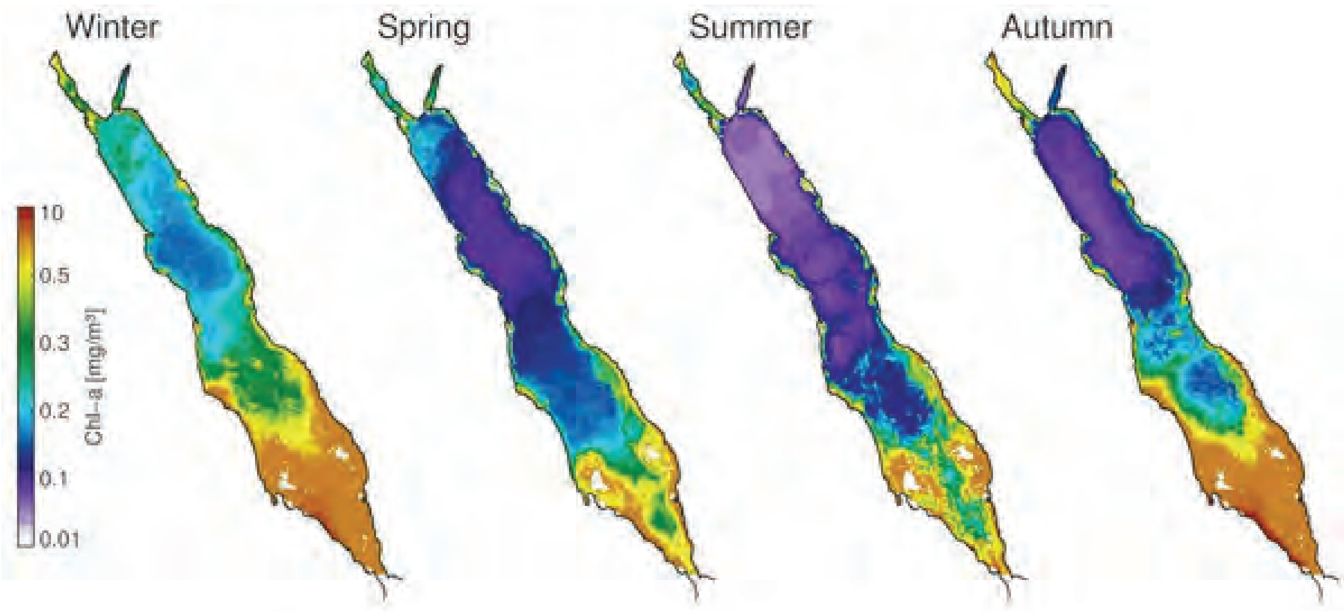

FIGURE 4: SEASONAL CHANGES IN CHLOROPHYLL-A CONCENTRATION (MG/L) IN THE RED SEA[3] FROMO MODIS 2003 – 2011.

Primary productivity may be increased locally as a result of the additional dissolved nutrients (e.g. nitrogen in the form of ammonium, which is converted to ammonia in seawater), added to the environment from fish biological processes (e.g. through excretion).

Faecal matter produced by the caged fish will be variable in size and density, which affects sinking velocity. As the Red Sea is highly saline sinking velocities will be slower than other sea areas, and the density of seawater will be higher, that may result in smaller particles remaining in suspension. Suspended materials will undergo bioprocessing by bacteria and will utilize oxygen from the water column, so a high level of suspended faecal matter may reduce water oxygen concentration locally. A good current speed through the cages will remove this waste.

Once feed and faecal matter has deposited on the seabed, bioprocessing will reduce the size of the particulates that are present. Winds and higher current speeds may re-suspend highly nutrient material from the seabed. Bioprocessing will continue as described above and act to reduce oxygen concentration in the water column. Similarly a good current speed will act to remove these particles from the cage area.

The extent to which faecal matter will remain in suspension or material will be re-suspended requires research given the environmental conditions present in the Red Sea and no specific data is available currently on the likelihood of such material having an effect on cage culture.

Source: Raitsos et al 2013 available at DOI: 10.1371/journal.pone.0064909 3

3.6. Current speed and direction

Current speed and direction is a critical physical characteristic of water that must be measured prior to the setting up of a fish farm. The three key biological effects of current speed are:

1) To distribute particulate waste materials from the cages (waste feed and faeces);

2) To remove (flush) dissolved wastes (e.g. excretory products such as NH_4 (NH_3); and

3) To ensure sufficient flow-through of water within the cages to replenish oxygen.

Balanced against these positive effects of having a site with a higher current speed it is important to consider that:

a) High current speeds will mean the fish have to expend more energy, and consume more oxygen, in order to simply stay in position within the cage, which can affect feed consumption and fish growth, and may affect the fishes feeding hierarchy leading to variable sizes of fish within a single cage;

b) High current speeds mean that feed may be washed out of the cages before the fish have a chance to consume it, which increases feed use and lowers Feed Conversion Ratio (FCR);

c) High current speeds will affect the cage infrastructure through stresses applied to the moorings and other components and cause net deformation (See section 4.3).

Biologically, there is no specific current speed value that is ideal for the fish. As fish are captive, too slow a current and fish will not have sufficient oxygen replacement within the cages, too fast a current and fish will expend too much energy on staying in position, and under either circumstance growth will be lower, and stress and susceptibility to disease will increase.

However, in some locations permitted biomass or production level at a site is often defined by current speed (and depth), because currents affect the distribution of wastes, which is perhaps the impact from cage culture at sea.

In Scotland, for example, salmon culture is defined through 3 current speeds with associated maximum biomass holding (Table 6) and such would be a good starting position for the KSA and could be adjusted as further information on coastal current speeds become available. Measurement of current speed (and direction) is required at the selection stage to ensure sufficient water flushing can occur, with mean current speed calculated from the resulting data. Mean current rather than maximum current speed is crucial, as a high percentage of quiescent water (speeds less than 2cm/s) is potentially damaging (through low water exchange and high local waste deposition), even when the maximal speeds are reasonably good.

TABLE 6: PROPOSED PRODUCTION RANGES BASED ON CURRENT SPEED (M/S) MEASURE ON SELECTED SITE

	(Current speed (m/s		
(Production (T	m/s 0.05 – 0	m/s 0.1 - 0.05	m/s 0.1 <
T 499 – 0	✓	✓	✓
T 999 – 500	-	✓	✓
T 1000<	-	-	✓

There are however, limits to current speed, both biologically and technically. Biologically speaking mean current speeds of greater than 30 cm/s will increase energy use in fish to retain position, increase feed use and lower growth.

Effects of current speed and direction on environment sustainability (waste deposition) is discussed further in Section 5.

3.7. Fouling

Although the Red Sea is oligotrophic with a low primary productivity and few macroalgal species, coral reef systems are highly productive areas, with growth of corals, coralline algae and other species, all of which may settle on cage infrastructure (mooring lines, cages and nets).

Settlement on nets can have a physical effect on the caged fish through abrasion when fish come into contact with nets. Abrasion can open wounds that can be subject to secondary infection with bacteria, fungus and other disease vectors. Wounded fish may also attract predators to the cages.

The primary fish welfare problem of fouling on cage nets is to reduce the size of the mesh opening, which reduces the speed with which water passes through the net mesh. Slow current through the net means oxygen is not being replaced as quickly as it is being used, especially during feeding, and oxygen concentration within the cage can reduce quickly and dramatically, creating stress for the fish and if not replaced quickly fish may die.

Fouling on nets (similar to all other structures in the sea) goes through a specific sequence of activity4:

1) Conditioning
2) Bacterial settlement
3) Build-up of Extracellular Polymeric Substance (EPS)
4) Micro-algal settlement
5) Macroflora and fauna species settlement

Fouling on nets can be reduced by applying a coating (typically copper oxide) to nets, which acts to kill any flora and fauna that settle, through copper oxide's toxicity. The useful life of the net is extended without the need to change the net too often, which is a process that is costly and increases stress in the fish. However, this must be balanced against increasing copper concentrations locally. No toxicity has been recorded in the fish when anti-fouling coating is added.

Alternatives include frequent net changes, but recognize that this induces stress in the fish.

It is not recommended that nets are cleaned *in-situ*. Devices do exist for cleaning nets *in-situ*, but large amounts of debris is created, some of which may remain suspended (see section 3.5) and/or the debris settles on the seabed near to cages adding to the impacts on the seabed. Removal to shore and drying in the sun, or having the nets cleaned at a cleaning centre are good alternatives. Please note that UV rays, in the long term (whether the net is in the water, or drying on shore), can affect net integrity and new nets need to be purchased as regular intervals.

When considering a site it is worth assessing other local structures to evaluate the extent to which settlement and fouling occurs locally. Importantly fouling of nets, in particular, can be managed so that the fish are not affected.

3.8. Algal Blooms

There is limited information available on the existence, frequency and intensity of algal blooms within the Red Sea, so the guidance here is limited also. One account shows that a Harmful Algal Bloom (HAB) of *Heterosigma akashiwo*, a toxic species, developed into a Red Tide in the southern Red Sea in 2010[5], possibly associated with increased nutrients from shrimp farming outflows. Touliabah et al[6] provided a general paper on phytoplankton species present in the Red Sea.

4 Source: Corner et al, 2007. Available at DOI: 10.1111/j.1365-2109.2007.01675.x

5 .Zakaria and Abdulrahman, 2012. Available at http://www.iopan.gda.pl/oceanologia/542zakar.pdf

6 Touliabah et al, 2010. Available at http://www.kau.edu.sa/Files/320/Researches/57386_27621.pdf

Above (Section 3.5) it was noted that the Red Sea is oligotrophic and chlorophyll-a concentration (used as a surrogate for phytoplankton biomass) within the Red Sea is low through most of the year. Fish farms release nutrient rich material into the environment, in the form of dissolved and particulate wastes, which can increase the productivity of waters around the fish farm. Where there are a large number of fish farms within the same area, cumulative effects can occur which increases the level of nutrient in the water column. However, further research is needed to establish to extent to which this phenomenon occurs within the Red Sea.

Plankton blooms can be catastrophic for fish farms, leading to large scale losses. When plankton blooms die and bacteria consume the algal mass, consumption of oxygen increases dramatically which can lead to local scale reductions in water oxygen concentration, which can affect fish stocks. When blooming, the microalgal species can cause an irritant to gill tissues, which reduces the capacity of the fish to take up oxygen from the water column. In some cases the blooming species may produce toxins and be toxic to fish (e.g. *Heterosigma akashiwo* from the above example).

Algal blooms can be sporadic and unpredictable, but as increased data becomes available it is recommended that fish farms do not locate in areas that have regular outbreaks of algal blooms.

3.9. Existence of other aquaculture

If conducting an assessment of a potential site, and other fish farms are located nearby (whether or not they are operated by a single or multiple companies), there must be an assessment of cumulative effects, for example, from the combined output of nutrients within the whole area being farmed. Assessment should also include whether or not currents are affected at the proposed site because of the presence of other farms, and whether there is a potential for transfer of disease from one site to another. This is particularly relevant for zoning where fish farms are likely to be closer together.

Some countries have introduced minimum distances between individual fish farms or between fish farm zones, but the extent of the distance is variable globally, from a minimum of 8 kilometers between individual sites for Scottish salmon farmers, to a few hundred meters between sites in Asia. Distances are primarily to ensure that disease outbreaks and parasites at one farm do not impact other farms directly, if possible.

Within zones, as operated within the KSA, it is important to estimate the carrying capacity (see also section 5) of the zone in terms of biomass to be produced, and based on this an estimate of the number of cages needed to grow this tonnage of fish, assuming a maximum stocking density within each cage. The size of the individual sites (in terms on number of cages and layout) can then be calculated, taking into account the environmental criteria related to mooring and cage design (Section 4). This will indicate the maximum number of sites that an area can hold sustainably. Within zones the physical distance between sites can vary (depending on the carrying capacity determination, number of fish farms and the size of the zone), but sites should, where possible, be not less than 1 km apart (on the surface – i.e. cages) so as to ensure there is no cross-over in mooring lines and anchors on the seabed.

The minimum area covered by a single site includes all visible components (cages and buoys at the surface) but also the physical area on the seabed in which the moorings and anchors are placed. Often, sites (and the associated licenses issued) have a total area that is 20 – 40% larger than the physical space occupied by the cages and mooring system, to ensure that for the installation of the cages there is some capacity for slight variability in the final positioning.

The spatial areas specified in any leases issued should not overlap.

The need for a physical distance between zones is a matter of debate and there are no specific criteria that can be given. Zones should not overlap, to avoid conflicts.

Proximity to other aquaculture operations is a consideration in site selection, especially if the sites are managed and operated by other companies, where management decisions may differ in response to, for example, a disease outbreak or parasitic infection and the need for treatment. If disease breaks out in a site, it will be important to inform the authorities and other local farmers, so that a comprehensive action plan can be implemented. It is important for the health and wellbeing of stocked fish that diseases are treated immediately and comprehensively, so as to avoid a situation in which the farm is treated, but an outbreak occurs at a neighboring farm, with the potential to have the disease transfer back to the farm almost immediately.

3.10. Proximity to rivers / water effluents / wadis

The extent of rainfall within the KSA means that the KSA's Red Sea coast does not have a large influx of freshwater, little if any localized salinity change from river input or large influxes of suspended material being added to the marine environment.

Rainfall can be high over short periods and wadis can become full very quickly and because riverbeds are dry for much of the year have the potential to transport high quantities of dust and suspended materials, and other larger materials (e.g. logs, tree stumps).

Although rainfalls are occasional and occur over very short periods it is recommended that farms will be located at least 0.5 km from wadi outlets, to avoid the potential collision or other nascent effects.

Impacts of desalination plants are considered above (Section 3.2), but as a general rule where heavy industry exists, and wastes enter, or have the potential to enter into the sea, such areas are best avoided.

4. Environmental criteria related to the cages and mooring design

In addition to the previously mentioned environmental aspects related to the fish biology and fish physiology (Section 3), there are other essential environmental criteria to be evaluated which have a relevant influence on the cage and mooring design (Figure 5) and on any other equipment that will be installed or used in the farming business.

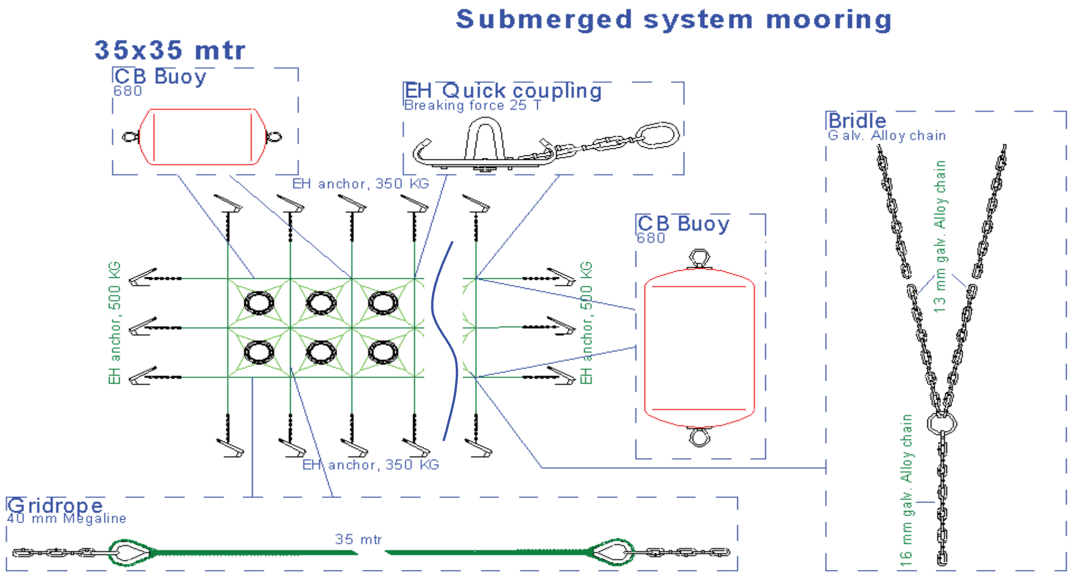

FIGURE 5:SCHEMATIC EXAMPLE LAYOUT OF CAGES AND MOORING DESIGN, INCLUDING MOORING EQUIPMENT.

4.1. Bathymetry / Water depth

Not all of the coastal waters of the KSA will have a water depth that is suitable for aquaculture development. Cage farming operates best in coastal waters that are not too shallow, depending on the net depth for example, and not too deep that it becomes logistically difficult to deploy moorings and other structures.

Figure 6 gives the overall depth ranges for the Red Sea as a whole.

The depth of water at the site is important for several reasons.

If the site is too shallow and subject to tidal variation and wind and wave action the net may be subject to abrasion on the seabed. The natural elongation of some plastic materials used in the netting production, such as nylon, can and usually does generate a “bulging (protrusion down)” in the central part of the net base due to the elasticity of the material which is affected by gravity. Stretching may increase if the net is fouled with algal and other growth. The minimum water depth therefore needs to be taken from the lowest point of the largest likely waves at low tide.

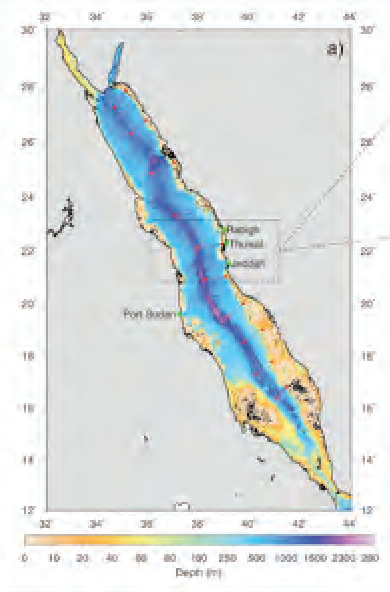

FIGURE 6: OVERALL BATHYMETRY OF THE RED SEA (FROM KAUST[7])

It is recommended that the water depth should be 2 times the overall net depth, which will eliminate any possible abrasion.

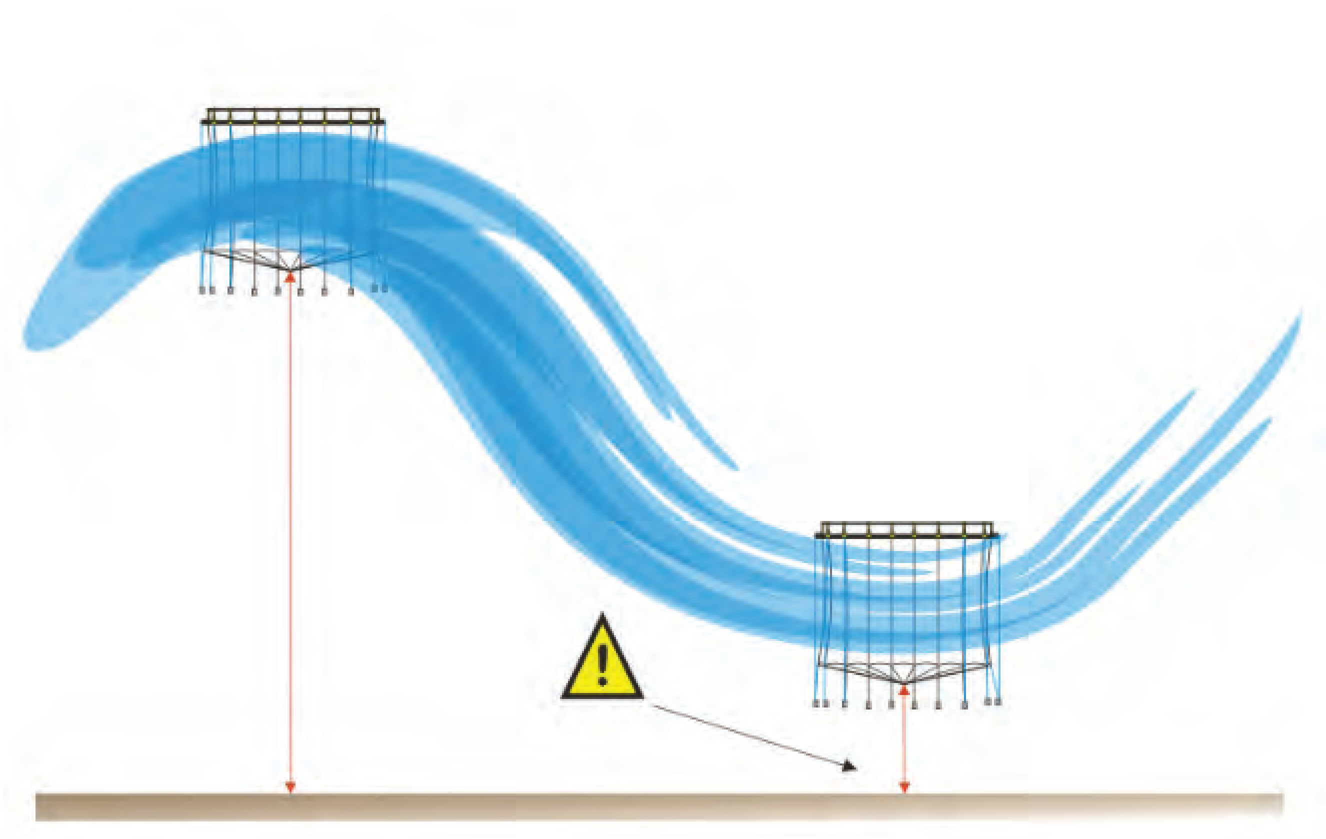

FIGURE 7: SEA BED DISTANCES FROM THE BASE NET ACCORDING THE WAVE HEIGHT

7 http://krse.kaust.edu.sa/spring-2010/mission.html

Bathymetry also dictates the mooring length (Figure 8), and consequently, the dimension of the fish farm license area. The greater the depth, the greater will be the length of the mooring ropes/chains to be used.

As a general rule the length of the mooring line can reach 3.5-4.2 times the depth when using sand anchors, although it is possible to decrease the length of the mooring line to 2.5 – 3.0 times the depth if using concrete block anchors (See box 1). The use of either will depend to a large extent on the underlying sediment conditions.

Box 1: Effect of anchor choice on lease area size.

The choice of using sand anchors or concrete block anchors will impact the area covered by the site.

In this example water depth is 30m and the fish farm has 20 cages of 90m circumference (approximately 30m diameter) arranged as 2 rows of 10 cages and having 20m between the cages, which means the cages would occupy an area of 80m by 480m (or 38,400 m^2). This is the visible part of the site, but the site includes the unseen mooring system.

If using concrete blocks for anchorage, the blocks would be located up to 90m from the cages in all directions (i.e. 3x water depth). This increases the site area to minimum spatial scale of 260m x 660m or 171,600 m^2, which is 4.5 times the size of the visible part alone.

If using sand anchors the anchors would be located up to 126m (i.e. 4.2x water depth). This would increase the minimum spatial area of the site to 332m by 732m or 243,024 m^2, which is 6.3 times the size of the visible cages. Using sand anchors can increase the lease area up to 1.4 times larger than using concrete anchors.

It should be noted however, that the sediment type plays a significant part in whether concrete blocks or sand anchors can and should be used. The spatial scales above are the minimum lease sizes for the example given. Often licenses are 20 – 40% larger than is occupied by the cages and mooring system, to give some flexibility in final positioning when the cages and moorings are installed

Importantly the licence application and leased area should reflect the full extent of the cages and the mooring system with some flexibility, and not just the visible part at the water surface.

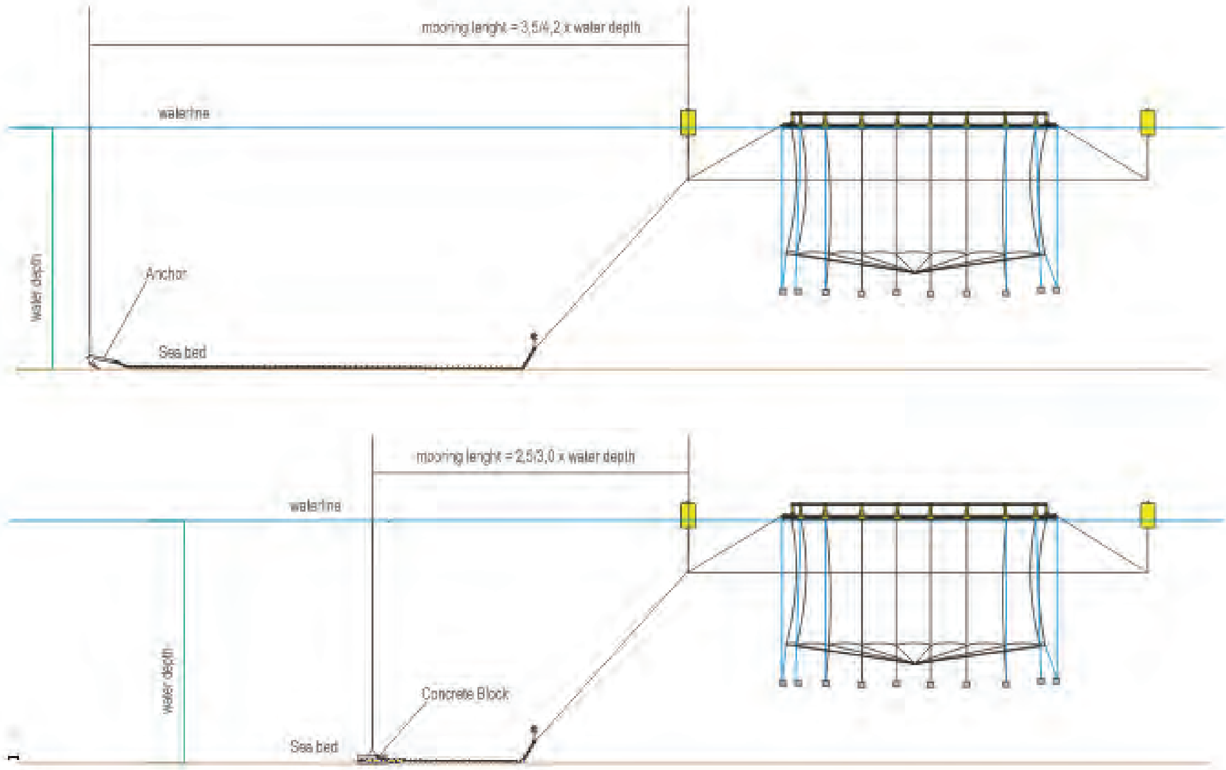

FIGURE 8: LENGTH OF THE MOORING LINES ACCORDING THE ANCHORING SYSTEM USED

Bathymetry influences the wave height. The shorter is the distance from the bottom of the sea surface the greater will be the height generated at equal intensity of wind. In the case of shallow water, the wave can also break (surf in the Figure 9). This phenomenon is extremely destructive to any fish farming facilities such as floating cages or feeding barges. The wave in this case represents a moving mass that causes continuous elongation stress on the mooring components. In selecting a site, among possible different locations having the same or equal exposure to the winds, it is a good practice to choose the deeper site.

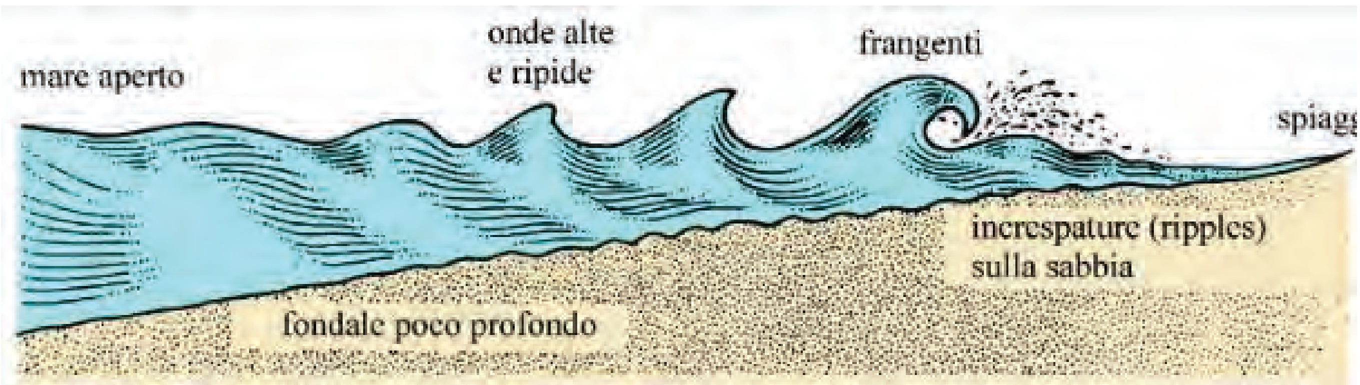

FIGURE 9: SURF GENERATION

Another phenomenon is the so called reflected wave or "return wave". It can happen even in very deep sites if the site is a very short distance from the coast, for example where the shore rises steeply as a rocky wall. In this case the wave collides against the rocky coast and reflects its power in a return wave which, once overlapping to the incoming following wave, duplicates its height and power. This can have destructive effects on the cages and especially on the nets, which can be seriously damaged by this kind of waves.

Sites which have a depth over 40 m increase the difficulty of carrying out underwater inspections, which must be made periodically by divers for maintaining the anchors and the mooring system. Although maintenance requires sporadic controls, for health and safety reasons it is not advisable that staff divers dive regularly below 40 m water depth. Even at shallower depths it will be necessary to employ a well-trained and experienced dive team, to carry out such mooring assessments.

Siting of fish farms can be executed on deeper water (for example this is typically the case in Norwegian fjords where sites are located in waters depths of up to 300m), but alternative methods of anchor retrieval are required, such as having a permanently attached riser buoy, from each anchor to the surface, which allows retrieval of the anchor by winch onto a boat deck, where maintenance can be carried out before the anchor is re-deployed.

4.2. Max wave height, direction and period

The wave height and the consequent main provenience are the most important phenomena to consider in selecting a site, either for the suitability for fish farming and for the choice of technology to use.

The waves are generally influenced by 4 main environmental factors:

- ➔ wind speed
- ➔ duration of the wind event
- ➔ Fetch (length of the direction in which the wind blows unhindered)
- ➔ Water Depth

The first three factors are directly proportional to the wave dimension (size), and the larger the value the greater will be the wave height.

In particular, the waves are measured in terms of:

- ➔ Wave height: from the crest to the trough, measured in meters (Figure 10).
- ➔ Wavelength: distance between two consecutive crests, measured in meters.
- ➔ Period: time gap between the passage of two consecutive crests, measured in seconds.
- ➔ Direction: the direction from which the wave comes , measured in degrees radial

The wave height is measured generally as a wave maximum (Hmax) or the maximum height between the crest of the wave and its trough, or as a significant wave height (Hs) or a wave with an amplitude equal to the width average of the highest third of the waves and a period equal to the average period of the waves predicted (Figure 11).

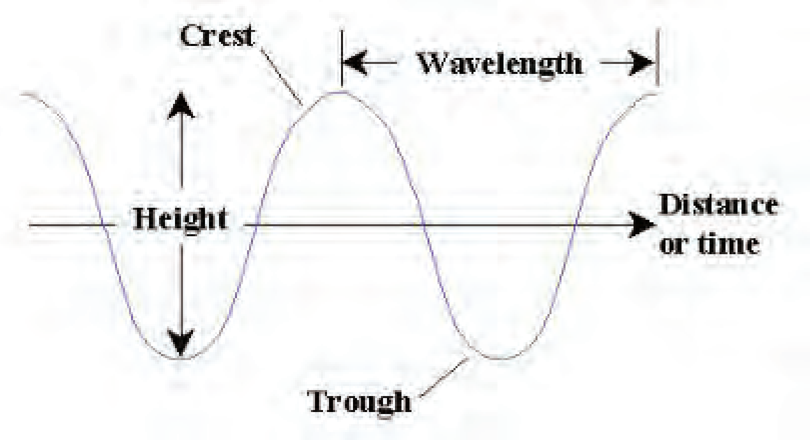

FIGURE 10: WAVE DIMENSION TERMS

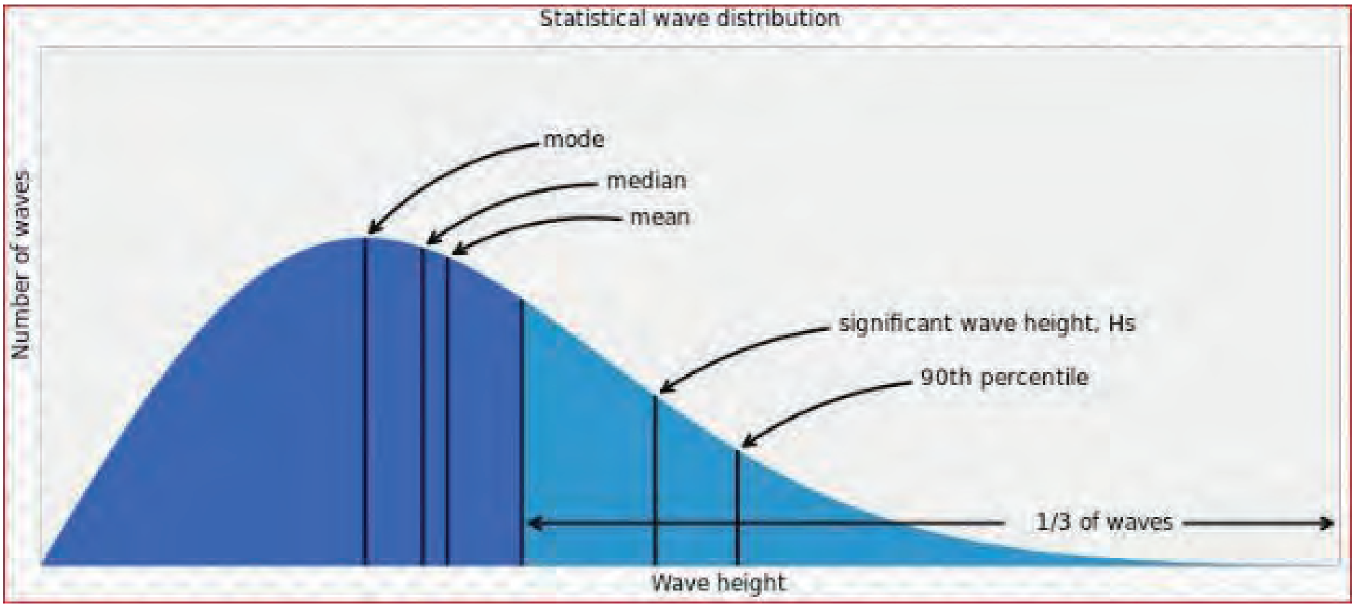

FIGURE 11: STATISTICAL DISTRIBUTION OF OCEAN WAVE HEIGHTS

The wave is therefore one of the major limiting factors in the development of marine fish farming in cages. In recent years, the material used to produce the floating cages is slowly moving from metal to high density polyethylene (HDPE). This plastic material is very elastic and it has excellent capacity of adaptability to the marine sine wave motion. In KSA, the use of high quality HDPE cages is recommended.

Naturally the diameter of the cage must be suitably sized according to wave height and wave period. It is generally recommended having large cages (in diameter) in sites where high waves are a recurring feature.

In sites where the waves are short in height, but with a very short period, the wear and tear of the materials increases dramatically. In this case, although the waves do not transfer a high energy to the structures, these are much more stressed cause by the higher frequency of the waves hitting the structure (higher wave period).

The main wave direction, indicated in degrees or radians, generally determines the orientation of the mooring system. It is always better to have a more detailed indication of the various directions of the waves at the selected site, to get a more accurate design of the mooring system.

In a grid mooring system, where there are generally several cages allocated as a single unit frame, it is generally accepted that cages should be oriented so that the short edge of the grid is in the same direction of the prevailing waves (Figure 12), while the long edge of the frame is facing the prevailing currents. If prevailing currents and prevailing waves have not orthogonal direction as shown in the figure below it is preferable that the mooring should be aligned considering the waves direction first.

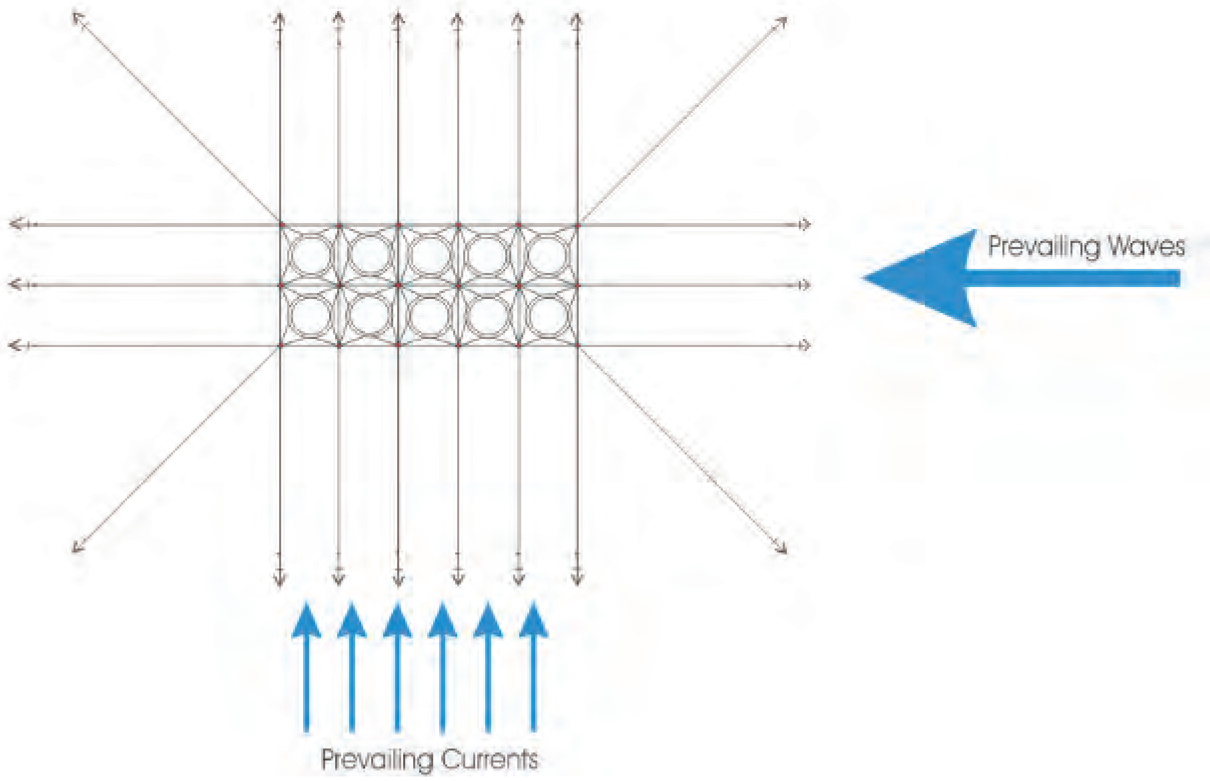

FIGURE 12: FISH FARMING MOORING ORIENTATION

Wave motion in shallow water is not the same compared to the deeper water sites.

Although the wave motion is composed of an orbital motion of particles in which the orbit radius decreases until it disappears when they gradually descend from the surface to the deep; in shallow water orbital motion is impacted by being in contact with the seabed, this friction causing horizontal movement in addition to the orbital movement (Figure 13). When wavelength is long (long wave) and it travels through a site where the water depth is less than half of the wave length, it is likely the influence of the seabed effect will increase, increasing horizontal movement of the wave and leading to more surf at the water's surface.

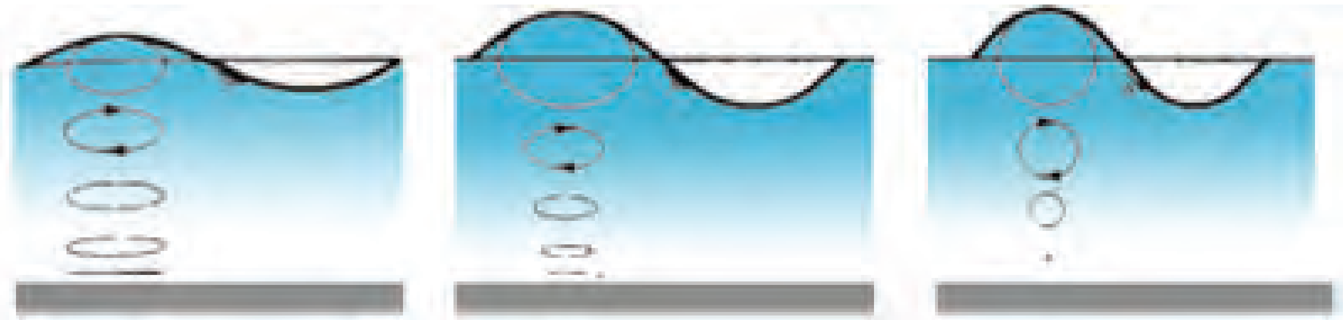

FIGURE 13: ORBITAL MOVEMENTS OF THE WAVE

Such areas are to be avoided for siting fish cages, as the movement of water through the fall of wave (Surf) causes high structural stress on the equipment and physiological stress on farmed fish.

4.3. Main current speed and direction

Slightly higher sea current speeds have a positive impact on the welfare of farmed fish and the environment that surrounds the farm, due to the increasing of the water exchange and consequent maintenance of an optimal level of oxygen in the cages and at the same time increasing dispersion of animal waste and uneaten feed and thus decreasing sedimentation. However, higher current speeds can adversely affect farming equipment.

Currents place an additional drag force on the mooring system over and above the already present and consistent wave force on the anchor components. This load may generate a knock-on effect on both anchors and concrete blocks, especially when the seabed is particularly hard and the mooring anchor sits on the seabed, rather than in the sediment.

In areas that are shallow, or where the sea bed is “soft” (e.g. mud and muddy-sand), the displacement of the seabed due to deep currents may erode the anchorage area, which exposes the anchor and significantly reduces the holding power of the anchor. Faring in such areas require continual re-alignment and re-deployment of anchors on a regular basis, so that overall position is maintained within the lease area.

Within the mooring system, the current also places a great stress on the buoyancy of the mooring buoys at the waterline. Higher currents result is an additional sinking force over the normal elastic mooring capability, which can lead to catastrophic breakage and loss of cages and fish.

Figure 8 shows that if cages are subjected to larger currents (black arrow) the net will generate a drag force that will be loaded on the mooring system; the buoys of the mooring system are subjected to a resulting downward vertical pull (red arrows) generated by the cumulative effect of loads on the bridle (or ange line) and mooring line (black line).This down ward load is contrasted with the upward buoyancy (green arrows) (cage A – Figure 14). If the buoys are too small for the larger current speed (cage B – Figure 15), buoyancy will be less than the downward load and the buoy and the cage collar will become submerged in strong current conditions.

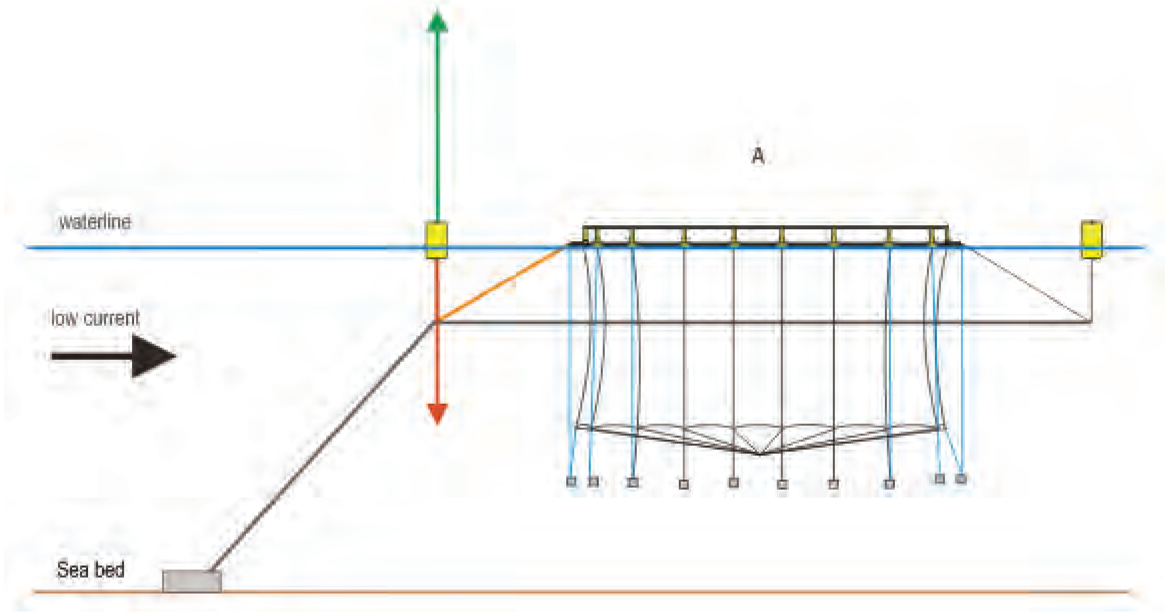

FIGURE 14: CURRENT EFFECT ON CAGE BY CORRECT ESTIMATED BUOY BUOYANCY

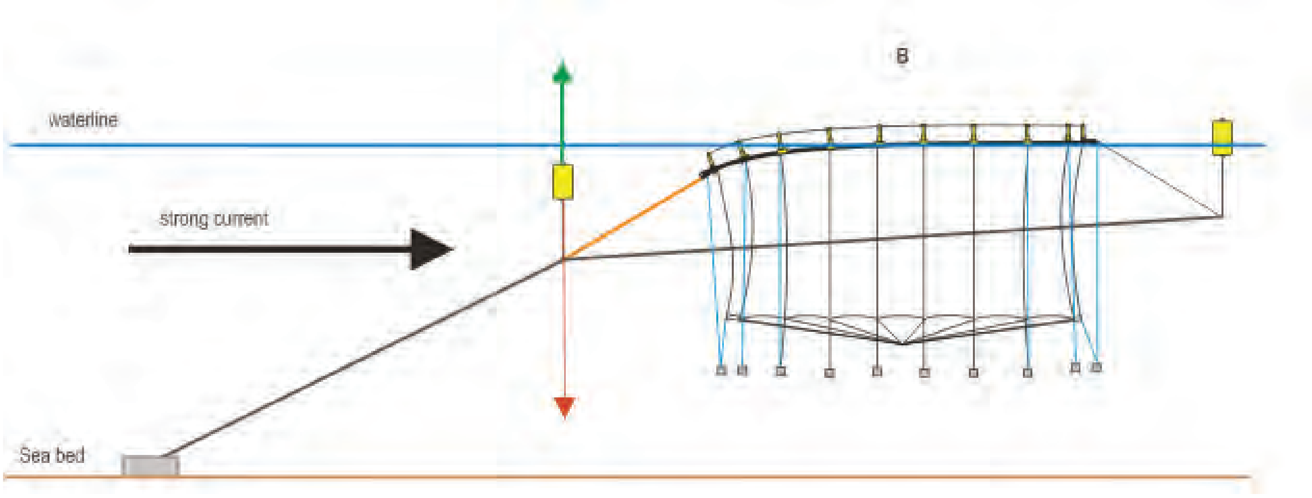

FIGURE 15: CURRENT EFFECT ON CAGE BY UNDERESTIMATED BUOY BUOYANCY

The orientation of the fish farm is also partially due to the current as well as to the incident main wave direction. When strong currents are orthogonal to the cage raft it is possible that a dangerous load is placed on the anchors in the middle area of the mooring (Figure 16). This can generate severe stress on the farming equipment (i.e. ropes, cage frames and nets) leading to possible breaks, with a loss of fish and equipment.

If currents are sufficiently strong, it is preferable to expose the short side of the grid to the incoming current direction so that the lowest number of cages are exposed to the main current, as mentioned previously (Figure 12).If it is not possible, the number of the mooring lines should be increased (duplicates added) especially within the central area of the cage mooring system (Figure17).

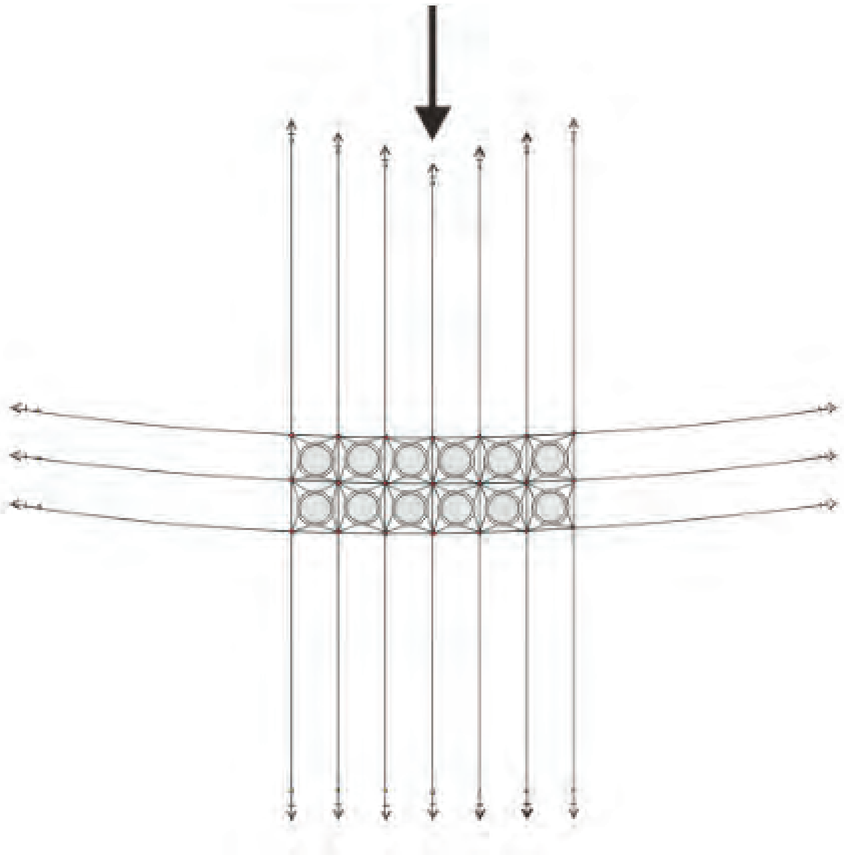

FIGURE 16: EFFECT OF THE ORTHOGONAL WAVE DIRECTION ON THE MOORING GRID SYSTEM

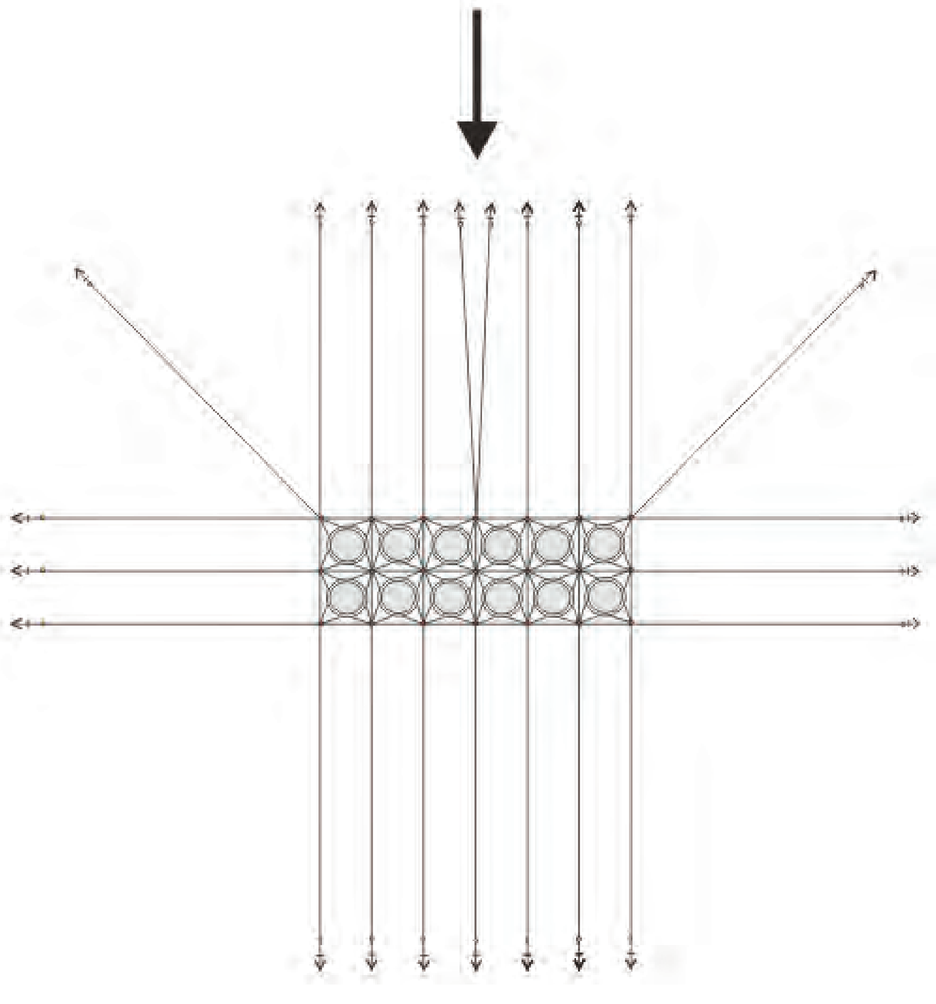

FIGURE 17: MOORING REINFORCEMENT LINES

The cage net is obviously one the most stressed part of the floating gravity cage system, creating a large surface area over which the incident current can impact. The stress (pressure) placed on the net will also increase the loading forces on the mooring system. Figure 18 shows the effect of increasing current speed on the deformation of nets (net shape) with the same mesh size, where the drag is increased as the current speed increases from A=0.3 m/s, to B= 0.5 m/s and to C = 0.7 m/s).

FIGURE 18: CURRENT EFFECT ON THE NET SHAPE

As direct consequence of deformation, the overall water volume within the cage is reduced, which reduces water exchange, and therefore oxygen exchange within the cage, having a direct impact on the health and welfare of the stock.

Stresses may be increased when the net mesh size is very small and / or the twine used in manufacture is thick. And stresses on the infrastructure may be compounded when there is a high level of fouling on the nets.

As shown above the increasing current causes a drop of the available volume of the net cage, and thus high current speeds forces the farmer to significantly increase the size of the ballast needed to keep the net hanging in position, through adding extra weights or installing a sinker tube (Figure 19).

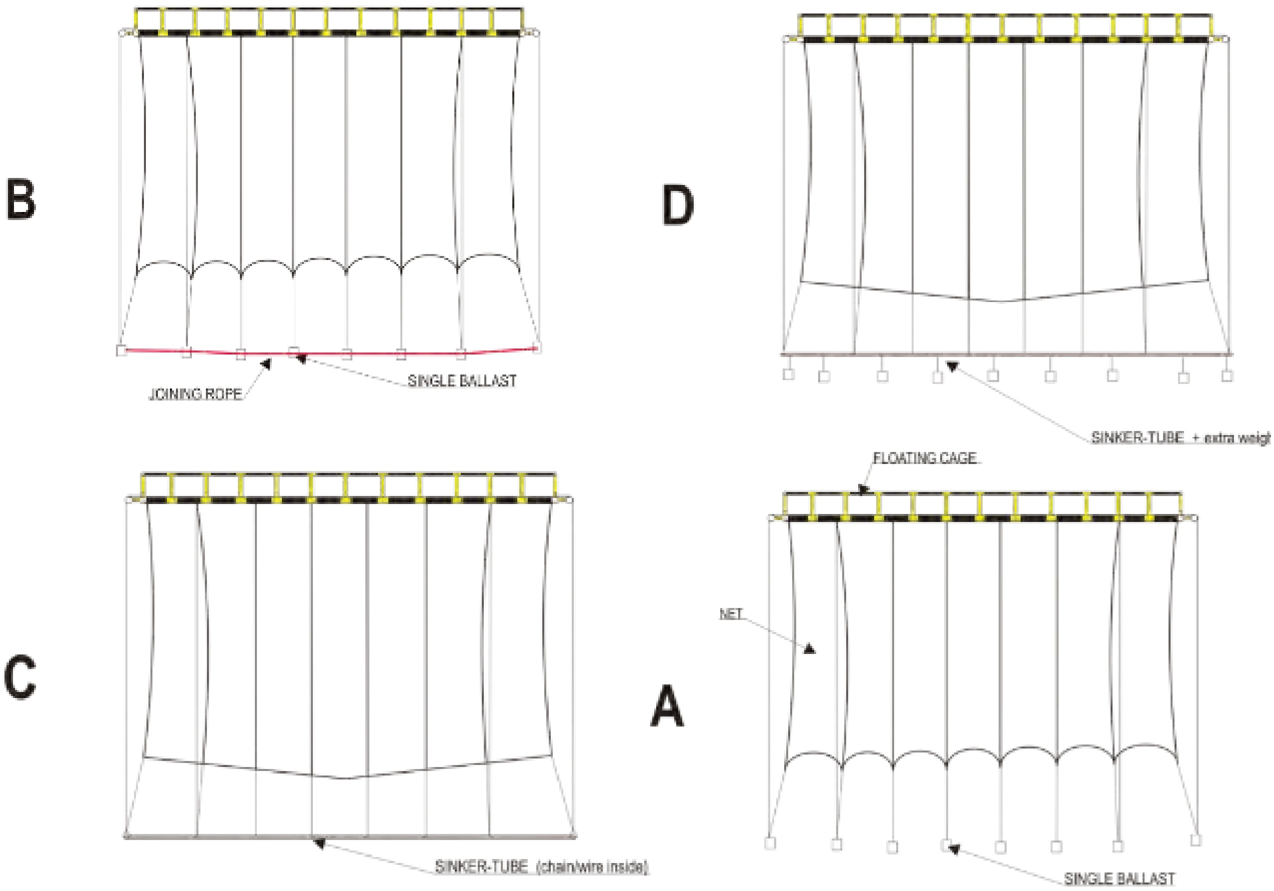

FIGURE 19: BALLAST SYSTEMS

4.4. Max Tidal height

The tidal height can affect the length of the mooring to the extent that the water depth should be considered the deepest at the maximum spring tide. The mooring system should be flexible enough to allow some movement up and down within the overall tidal range at the site.

In the Red Sea the tidal range varies between 0.3 and 0.6m, depending on location.

4.5. Main wind speed and direction

As mentioned above wind is the major contributor to wave production, and it is therefore crucial to know and to understand the likely intensity of the wind and its direction, which will indicate the origin and intensity of the wave propagation through the site.

Surface winds act on exposed parts of the farming equipment, it increases abrasion and wear and tear, mostly between the net and the net supporting structures. Winds may also seriously damage the bird nets protection, as well as affecting the stability of their supports.

Winds more generally can hinder or make the daily fish husbandry operations of the personnel both on boats and cages more difficult.

The wind is measured in knots or km/h, but can also be classified on the basis of a "Beaufort scale" as indicated in Table 7.

TABLE 7 WIND FORCE SCALE: BEAUFORT

Beaufort wind force scale

Specifications and equivalent speeds

Beaufort wind scale	Mean Wind Speed		Limits of wind speed		Wind descriptive terms	Probable wave height in metres*	Probable maximum wave height in metres*	Seastate	Sea descriptive terms
	Knots	ms^{-1}	Knots	ms^{-1}					
0	0	0	<1	<1	Calm	-	-	**0**	Calm (glassy)
1	2	1	1–3	1-2	Light air	0.1	0.1	**1**	Calm (rippled)
2	5	3	4–6	2-3	Light breeze	0.2	0.3	**2**	Smooth (wavelets)
3	9	5	7–10	3-5	Gentle breeze	0.6	1	**3**	Slight
4	13	7	11–16	5-8	Moderate breeze	1	1.5	**3–4**	Slight–Moderate
5	19	10	17–21	8-11	Fresh breeze	2	2.5	**4**	Moderate
6	24	12	22–27	11-13	Strong breeze	3	4	**5**	Rough
7	30	15	28–33	13-17	Near gale	4	5.5	**5–6**	Rough–Very rough
8	37	19	34–40	17-21	Gale	5.5	7.5	**6–7**	Very rough–High
9	44	23	41–47	21-24	Severe gale	7	10	**7**	High
10	52	27	48–55	25-28	Storm	9	12.5	**8**	Very High
11	60	31	56–63	29-32	Violent storm	11.5	16	**8**	Very High
12	-	-	64+	33+	Hurricane	14+	-	**9**	Phenomenal

FIGURE 20: NET FOULED

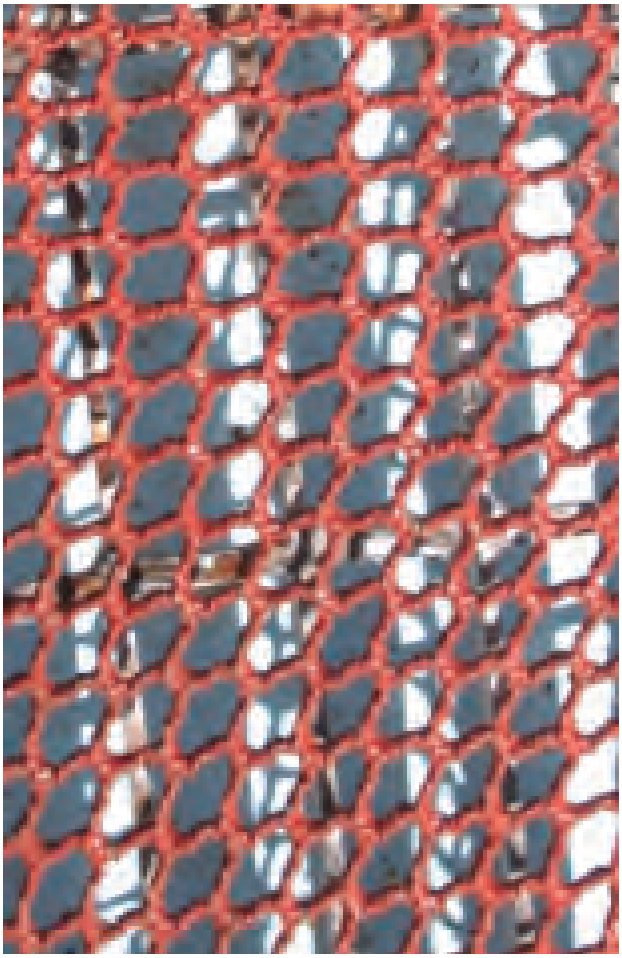

FIGURE 21: NET WITH AF COATING

4.6. Fouling

Fouling is one of the most important issues in Mariculture and it can cause serious damage to the net, if not properly managed.

Fouling is a mixed composition of various marine flora and fauna; organisms such as microalgae, bivalves, corals, nudibranchs, sponges, bryozoans and barnacles; that attach themselves to the net and all submerged structures below the water's surface (Figure 20), and that can then cause physical damage or problems in production.

Physical impacts:

Sometimes they stick to the net as concretions with very sharp shells, which can cause serious damage through contact and abrasion on the net and to the ropes, leading to fraying and eventual breakage. Furthermore, if maintenance and cleaning is not performed periodically and properly, net weight is increased dramatically, leading to additional stress on the structures holding the net in place and on the surface collar. This event makes the net more difficult to handle when a replacement /change of the net is required with a consequent increase in stress of the fish stocked in the cage during the change process.

Production impacts:

The fouling organisms attached to the net cause clogging of the net mesh and water cannot flow through the cage efficiently and water exchange between internal / external areas of the fish cage is reduced. This causes a drop in dissolved oxygen exchange which impacts the growth and health of the fish and increases mortality (due to low oxygen). Where the net is covered in hard-shelled organisms fish may be cut and abraded, which may lead to secondary infection and increase susceptibility to disease and higher mortality. Fouling is particularly a problem when fish are small as the net mesh is smaller and can be more quickly clogged; since small fish require proportionately more oxygen than larger fish these may therefore be more susceptible to period of low water exchange.

In areas where fouling will be a problem it is common practice to treat the nets with an antifouling coating (Figure 21), where the main biocide ingredient is the copper oxide, which may be toxic for the most sensible aquatic animals and plants (and hence its ability to reduce fouling). The quantity (%) of the heavy metal (copper oxide) in commercial antifouling products sold on the market generally reflects the limits allowed by Health and Safe Regulations.

4.7. SEABED MORPHOLOGY

It is essential to identify the morphology of the seabed so that the dimensions and the type of mooring system used can be readily identified. The bottom type composition determines the type of anchorage required.

In soft or “movable” sediment (e.g. Figure 22) (such as a sandy and / or muddy seabed) it is preferable to use anchors (plow anchors) (Figure 25). The thickness of a soft seabed layer should be evaluated in order to allow the anchor to sink firmly (H – Figure 24); seabed thickness should be at least few meters to allow the anchor in being properly dragged into the seabed (1 – Figure 24 and Figure 26). Deep penetration is required to ensure the forces being applied to the anchor by the cage infrastructure is offset by the “bite” on the anchor itself (4 – Figure 24).

Where the sediment consists of hard or rocky bottoms (Figure 23), and where the anchors would struggle to work correctly, it is a good practice to use gravity anchors (such as concrete blocks; Figure 27) which must be correctly manufactured.

Concrete block anchors should be manufactured with an inner steel reinforcement (Figure 28), have a wider base than height (W >H - Figure 29), have additional protruding steel rings (b – Figure 29), have a pipe tunnel passing through for possible chain input(a – Figure 29) and have a lenticular shape at the base (c – Figure 29).

These build details are used to increase concrete block performance by increasing its grip on the bottom and at the same time extending the lifetime of the component.

FIGURE 25: ANCHORS

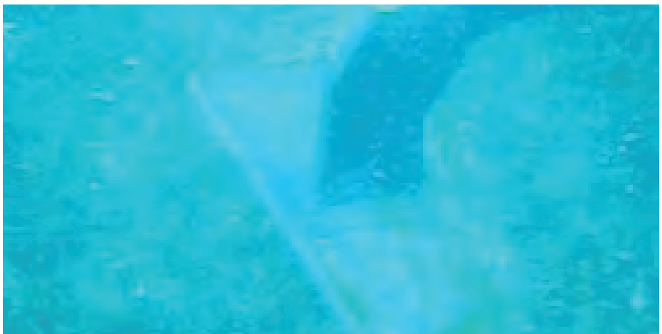

FIGURE 26: ANCHOR DIGGING ON THE SEABED

FIGURE 22: SOFT SEABED

FIGURE 23: ROCKY SEABED

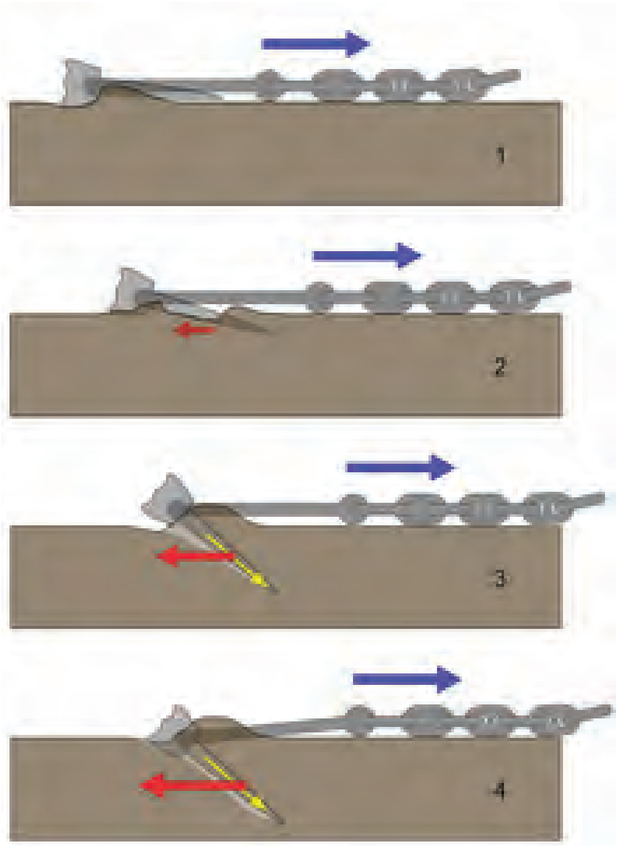

FIGURE 24: THE ACTION OF A STOCKLESS ANCHOR BEING SET[1]

[1] Tosaka: www.wikipedia.org

The seabed, whether it is sand or rock, it can also cause abrasion on the deeper mooring components that are in contact with the bottom. For this reason ropes should be kept within the water column and the connection to the anchor made using robust chain.

The seabed rarely presents homogeneity, and it is possible to find rocky areas alternating with sandy- muddy areas. In this case it is crucial to make a survey by echo- sounder in order to verify the existing seabed morphology. Figure 30shows an option for surveying using a basic path to make a simply and correct transect study of the area where a fish farm will be installed.

FIGURE 27: CONCRETE BLOCKS INSTALLATION

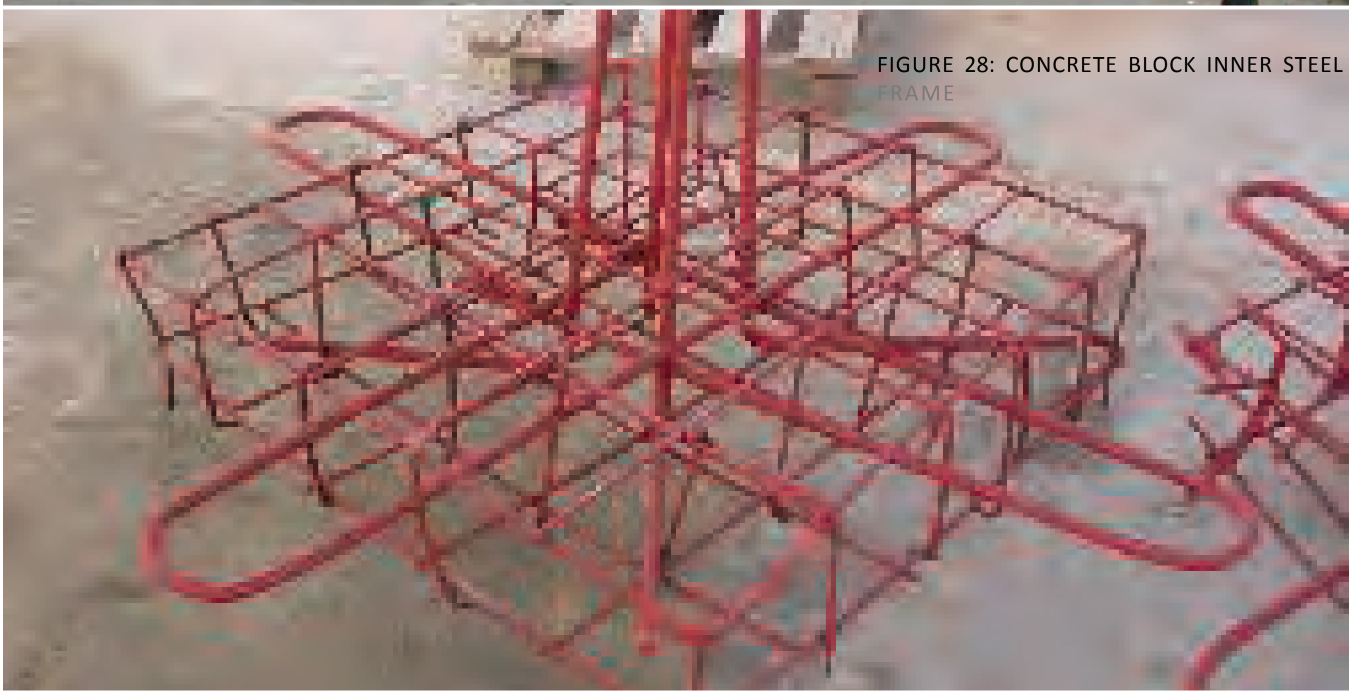

FIGURE 28: CONCRETE BLOCK INNER STEEL FRAME

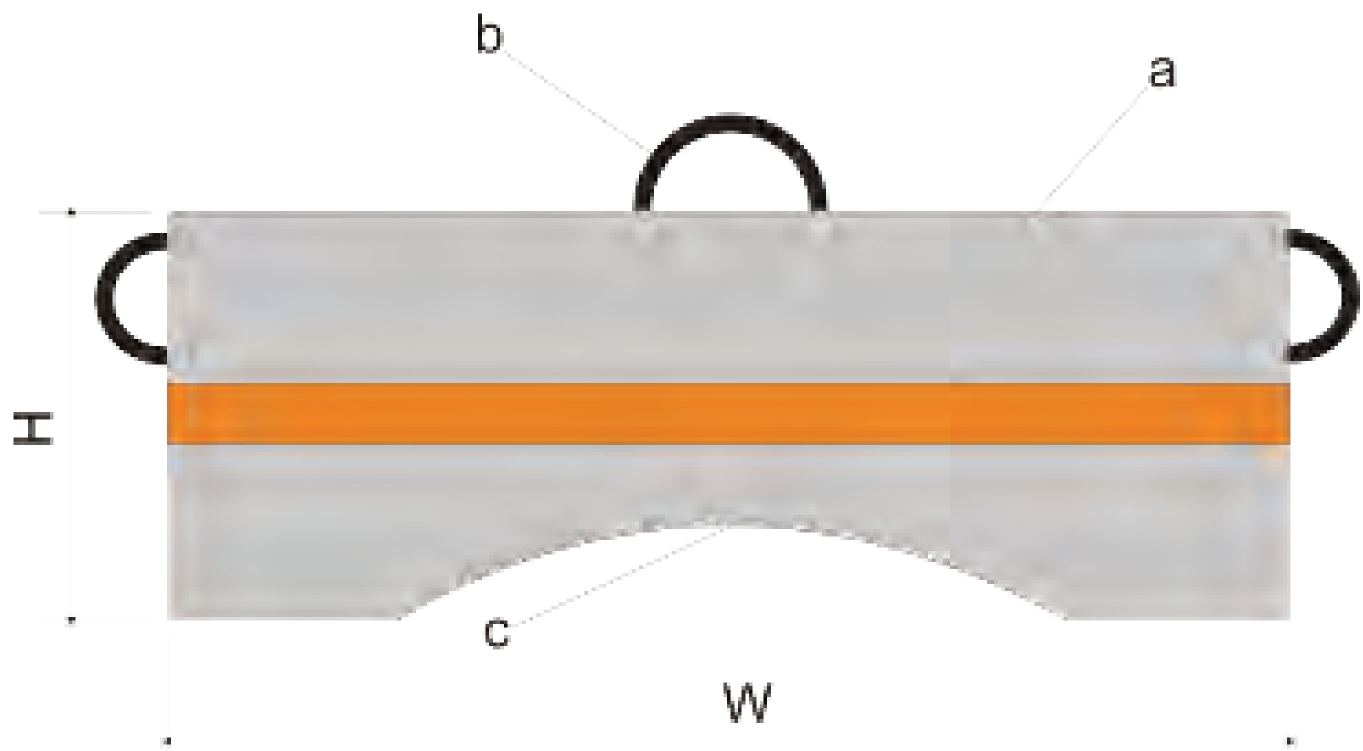

FIGURE 29: CONCRE BLOCK LAYOUT SUITABLE FOR SANDY SEABED

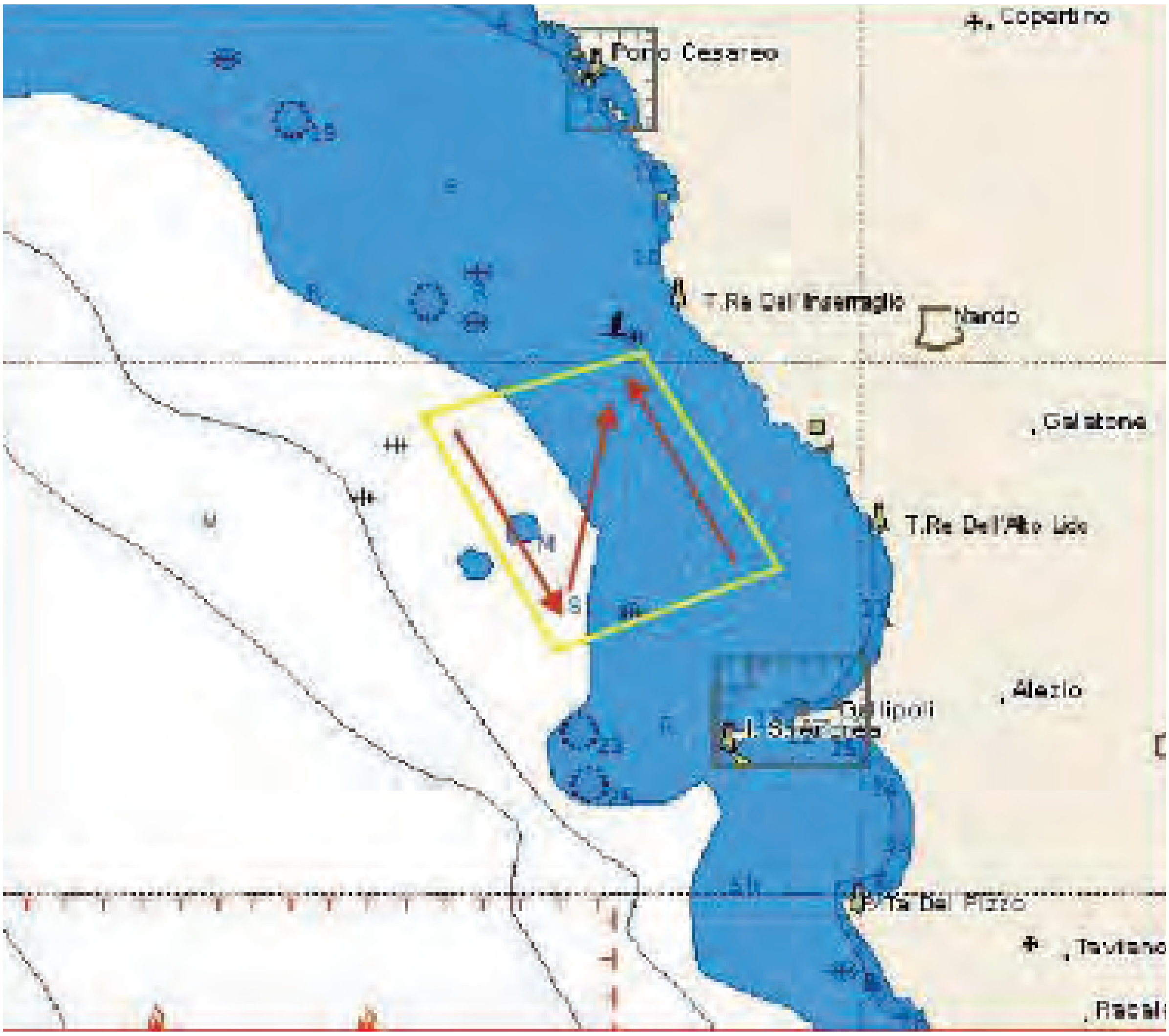

FIGURE 30: SEABED SCANNING SYSTEM WHILE SURVEYING NEW SITE

5. Environmental criteria related to environmental sustainability

The long term environmental sustainability of a fish farm development is defined, almost explicitly, in terms of the impact that the farm will have on the local and wider environment, and whether that impact has serious negative effects, damages the environment beyond acceptable levels, or has a negative feedback into the farm itself.

In selecting a site that will be sustainable on the long term the principles applied through the Ecosystem Approach to Aquaculture (EAA)[8], which supports articles 9 and 10 of the Code of Conduct for Responsible Fisheries (CCRF)[9], should be considered. EAA is defined as "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".

More broadly environmentally sustainable aquaculture development implies that aquaculture should not create significant disruption to the natural ecosystem functioning, cause loss of biodiversity or create substantial pollution. The latter implies, and it is worth stating here, that fish farming does and will have an impact on the environment and there is no reason to assume otherwise. As open systems of culture, wastes in the form of particulate feed and faecal materials and dissolved excretory products, enter the environment directly and therefore will have some level of impact. It is the extent of the impact that is important, minimizing or otherwise mitigating against the impacts; in site selection and more generally for environmental sustainability.

In this section we briefly discuss carrying capacity assessment, impacts of nutrient deposition, fragile ecosystems and fish farm sites as fish aggregation devices. This section specifically provide general guidance only, with defined criteria needing to be established locally.

5.1 CARRYING CAPACITY ASSESSMENT

Evaluation of site selection and carrying capacity for aquaculture has recently been published by the Food and Agriculture Organization[10]. In this review and the references cited therein Carrying Capacity can be defined in a number of ways, each complimentary in trying to establish the maximum production that a site, zone or ecosystem can reasonably sustain in the long term. In this document Carrying Capacity is defined under 4 categories, which are summarized as follows:

- *Physical Carrying Capacity* determines overall development potential based on physical features of the environment without consideration of limitations and regulations. In its purest sense it is used to identify zones that would be suitable, but without evaluation of the limits that might apply within a water body.

- *Production Carrying Capacity* determines the maximum aquaculture production possible and is typically applied at site level, taking account of the likely feed use, FCR and other management activity to work out what level of production is possible at any given site, and will include within this an estimate of economic requirements, to insure the necessary investment for a particular site at a certain level of production is available and secure.

- *Ecological Carrying Capacity* is the magnitude of production that can be implemented without leading to significant negative changes to the environment and the ecological processes, species, populations, communities and services.

- *Social Carrying Capacity* is the amount of aquaculture that can be developed without social impacts.

In the context of aquaculture site selection the data that is needed to evaluate each of these carrying capacity components is variable and FAO provide a non-exhaustive list (Table 8).

8 Available at http://www.fao.org/docrep/013/i1750e/i1750e01.pdf

9 Available at http://www.fao.org/docrep/005/v9878e/v9878e00.htm#9

10 Ross et al, 2013, Availableat http://www.fao.org/docrep/018/i3322e/i3322e.pdf

TABLE 8: SOME DATA REQUIREMENTS TO EVALUATE DIFFERENCE CARRYING CAPACITIES (ABRIDGED FROM ROSS ET AL 2013)[11]

Farming system	Physical carrying capacity	Production carrying capacity	Ecological carrying capacity	Social carrying capacity
System 1: Coastal marine cages	Wind Waves Currents Depth Temperature Salinity Infrastructure Etc.	Temperature Salinity Diet type Feed regime Investment costs Markets Etc.	Critical habitats Biodiversity Eutrophication indicators EIA data in general Visual impact Etc.	Sea and coastal access rights Access to capital Beneficiaries Workforce Etc.

Conducting studies to evaluate carrying capacity are complex, for example to determine site and zonal production capacity, whilst ensuring that ecological carrying capacity is not surpassed based on (typically) environmental quality standards (EQSs) that have not been formally tested within the KSA. However, certain data collection can be carried out by companies, through measurements on site that can then feed into a better understanding of the overall carrying capacity.

5.2 NUTRIENT DEPOSITION

Perhaps one of the largest impacts from marine cage farming is the deposition of particulate wastes from the cages onto the seabed. Wastes come in the form of uneaten feed and fish faeces, which distribute on the seabed.

The quantity of particulates and the spatial extent of deposition is a complex issue, affected by:

- Fish physiology - ability of fish convert feed into biomass and quantity of faeces generated by each fish species;
- Quantity of feed added, and an estimate of the amount that remains uneaten;
- Current speed – which distribute wastes horizontally in the water column;
- Settling velocity – rate at which the particulates sink which is affected by particle size and density relative to seawater and the salinity and density of seawater;
- Water depth – where deeper water increases the time for settlement and allows a larger distribution of wastes, and where shallower water means the seabed may be affected by wind and waves which can re-suspend settled materials that can be further transported based on the current speed; and
- Wild fish - and the extent to which waste materials are consumed before hitting the seabed

The quantity of wastes can be estimated through a mass-balance approach, in which estimates of fish biomass and Feed Conversion Ratio (FCR) are used to estimate total feed input, whilst outputs in terms of waste feed, faeces, respiratory and excretory waste and output in growth are calculated (Figure 31). Calculations are generally made on nutrient components carbon (Box 2), nitrogen and potentially phosphorus.

.Ross et al, 2013, Available at http://www.fao.org/docrep/018/i3322e/i3322e.pdf, p28 11

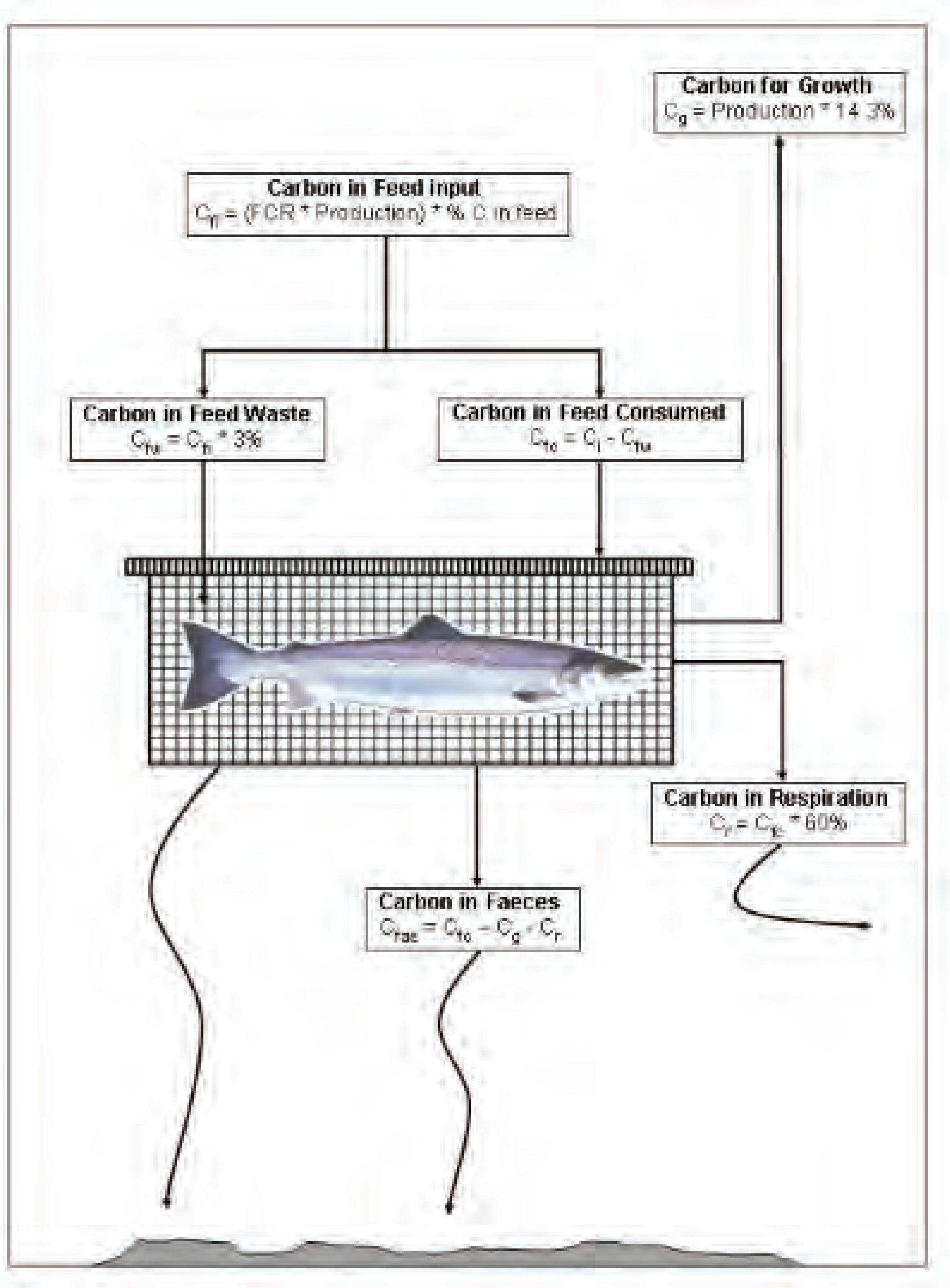

FIGURE 31: MASS BALANCE CALCULATIONS FOR CARBON, EXAMPLE FROM SALMON AQUACULTURE.

Box 2: Example estimate of carbon waste from a cage farm through Mass Balance calculations:

Mass balance calculations account for input and outputs from a system and balancing to elements so that they match (no gains or losses), in this case based around carbon from a fish farm, to explain where the carbon added goes and how much goes there, in this example baed on Figure 31 (but with simplified values):

Carbon in Feed input = (FCR x Production) × % carbon in feed

Carbon in Feed waste = Carbon in feed input × % Feed uneaten

Carbon in Feed consumed = Carbon in Feed input - Carbon in Feed Waste

Carbon in Growth = Production × % Carbon in Fish

Carbon respired and excreted = Carbon in feed consumed × % Carbon respired and excreted

Carbon in Faeces = Carbon in Feed Consumed – Carbon in Growth – Carbon respired and excreted

Worked example:

Production = 1000T

FCR = 2

% feed uneaten = 10%

% Carbon in Fish = 14%

% carbon in feed = 50%

% Carbon respires and excreted = 60%

Thus:

Carbon in Feed input = (2 x 1000) x 50% = 1000T

Carbon in Feed waste = 1000T × 10% = <u>100T</u>

Carbon in Feed consumed = 1000T – 100T = 900T

Carbon in Growth = 1000 × 14% = 140T

Carbon respired and excreted = 1000T × 60% = 600T

Carbon in Faeces = 900T – 140T – 600T = <u>160T</u>

In the above example the values used would need to be estimated or calculated for the specific fish species being grown, and are estimates only for a general fish. The two key values above are underlined and represent 260T of carbon being added to the environment per 1000T of fish produced. These value are significant and will deposit on the seabed, increasing seabed nutrient concentrations. In addition some 600T of carbon will enter the environment as dissolved waste, mostly in the form of carbon dioxide.

Distribution of particulate wastes in the environment can be evaluated (Figure 32) to give an overall estimate of the spatial extent to which waste feed and faeces will settle on the seabed. The larger mass of faeces deposited (see Box 2) will travel further due to its slower sinking velocity (smaller mass and density) than feed pellets. Overall a generalized picture of the likely settlement pattern can be established (Figure 33)

However, it should be noted that water depth can be variable across a site, water does not move in one direction and changes at different states of the tide (or wind), current speed and direction can change with depth, and faecal waste (in particular) are variable in size and structure and have variable sinking rates, as do feed pellets.

Thus more complicated assessment of waste dispersion must be carried using computer models, such as MERAMOD[12], which are able to handle variability in time and space.

In site selection terms the distribution of waste is a specific issue for the KSA, as fish farms are liable to be located in close proximity to coral reef systems and it will be important to ensure that corals are not covered by wastes being deposited from fish farms. It is important that current speed and direction are measured at the proposed site and water depth recorded so that some estimate of the likely horizontal displacement of feed and faecal waste can be made, to ensure the cages are not located too close to the reef system. No specific criteria can be given, as it will depend from site to site.

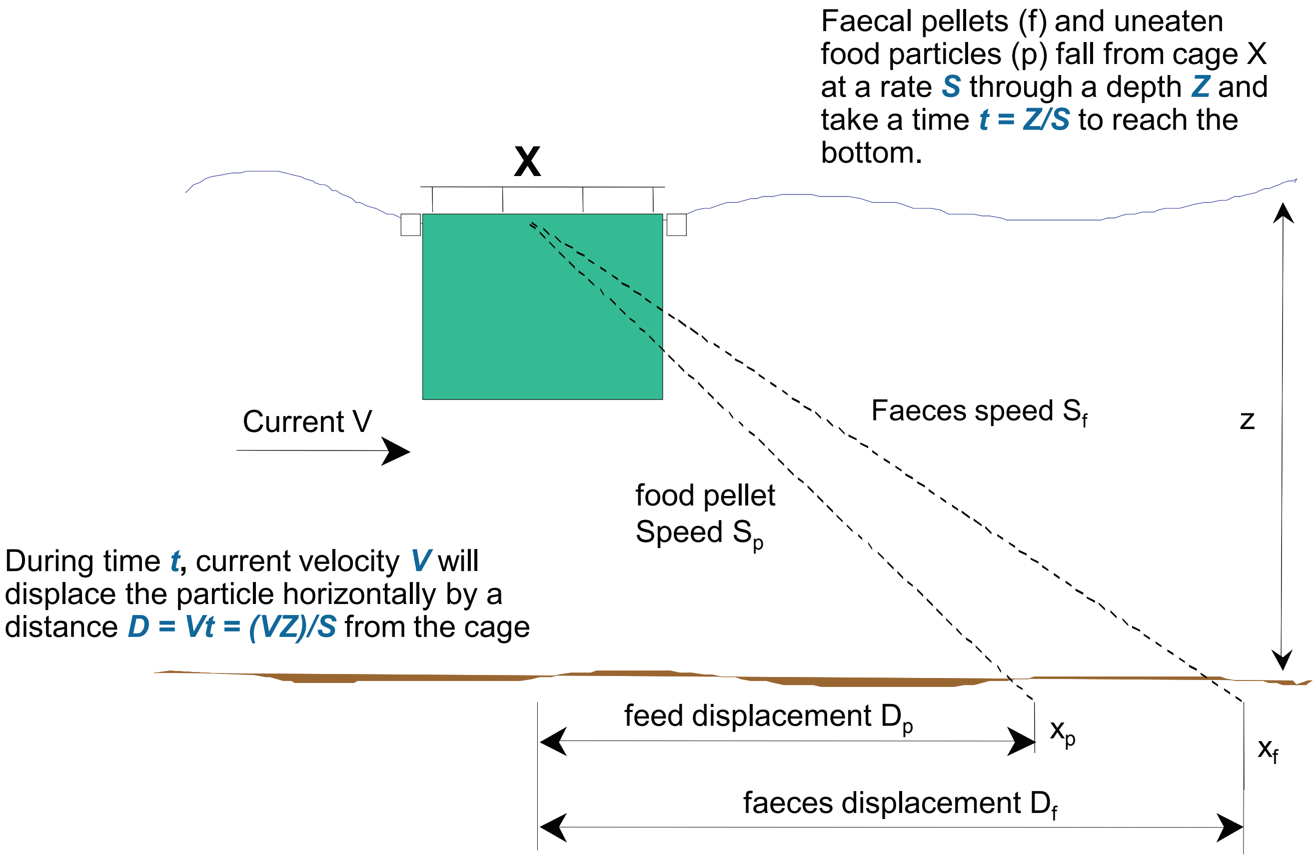

FIGURE 32: DISPERSION OF WASTE FEED PELLETS AND FAECES.

12 Further information at http://www.ecasatoolbox.org.uk/the-toolbox/eia-species/models/meramod.pdf

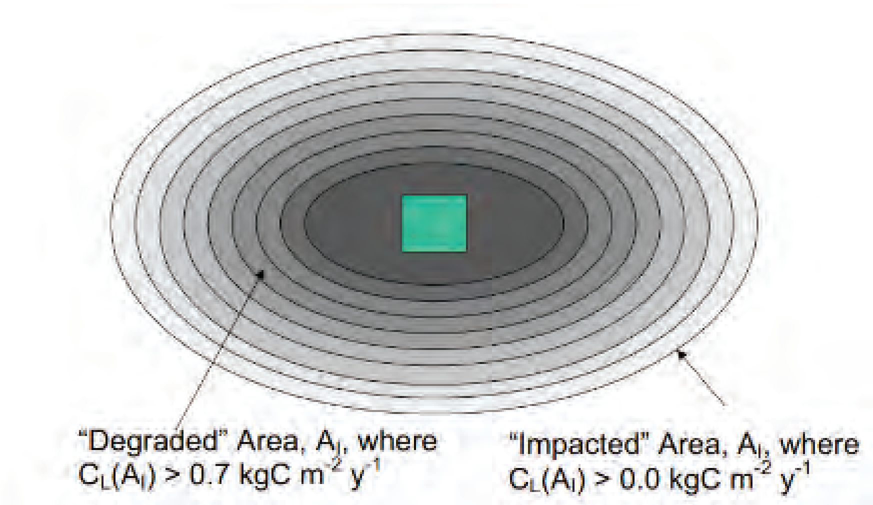

FIGURE 33: SCHEMATIC DIAGRAM[13] SHOWING SETTLEMENT OF WASTE FEED AND FEACES ON THE SEABED UNDER A FISH FARM (IN GREEN), RESULTING FROM VARIABLE PARTICLE SETTLING VELOCITIES. TEXT IDENTIFIES ESTIMATES OF AREA OF DEGRADATION BASED ON DEPOSITION OF 0.7 KGC/M^2/YR, WITH HIGHER IMPACT NEAR TO THE CAGES AND LESSER IMPACT FURTHER AWAY. VALUES FOR KSA WOULD HAVE TO BE TESTED AND VERIFIED.

Without explicit knowledge of water depths and current speeds at potential sites within KSA it is not possible to give likely spatial distribution of wastes. Box 3 gives an example to show how an estimate of displacement distance can be estimated.

Box 3: Estimating dispersion distance of sea bream faecal waste from a cage culture operation

Sinking velocity of sea bream faecal pellets is thought to range between 0.05 and 3.94 cm/s1 with an average of 0.48cm/s.

At a water depth of 30m (Z in Figure 32) and the average settling velocity identified above (0.48 cm/s; Sf in Figure 32) particles could take as much as 100 minutes to reach the seabed.

At an average current speed of 10cm/s (V in Figure 32) sea bream faecal matter could be dispersed horizontally over a distance of approximately 600m.

In reality faecal particle size is variable, and smaller particles would deposit further away whilst heavier particles of faeces, and feed pellets, would settle within this distance. Current speeds and water depths around the site will also be variable in time (change of tide, winds) so an accurate picture can only be established through modelling.

Distribution of waste is important for environmental sustainability in that damage can be done to the seabed if deposition below the cages is high. Deposited particulate matter changes the sediment chemistry through increased bacterial oxygen demand to process the particulate matter, and in high deposition areas sulphide reduction and methanogenesis can occur leading to production of hydrogen sulphide and methane respectively, both of which are toxic to aquatic life. It must be stressed that these are extreme and if they occurred it means the site is not really suitable for aquaculture. Good site selection and controlling waste through careful feeding, for example, reduces the likelihood of such extreme conditions occurring.

Source Gillibrand et al 2002, available from http://www.scotland.gov.uk/Uploads/Documents/Report63.pdf 13

Deposition of nutrient rich material also changes benthic biology. Under standard conditions species in and on sediments live in equilibrium with the environment responding to competition for space and resources, sediment chemistry, to grain sizes present and so on. When excess nutrients are added to the system there is a tendency to reduce species diversity in higher depositional areas, but increase diversity in transitional areas (moderate deposition), before returning to normal at some distance from the cages. Type of species and their response will vary with sediment type (mud, sand, rock). It is therefore important that some form of survey is carried to establish the normal conditions prior to the fish farm being operational, and to monitor the site for changes that occur during the years of operation.

5.3 Fragile ecosystems

Following on from the outline above (section 5.2) a short note on coral reefs and other potentially fragile systems that could be impacted by cage farming.

In some senses the Red Sea coast of the KSA is a fragile system, in that waters are oligotrophic with a low primary productivity. The Red Sea coast maintains ecosystems that are fragile such as sea grass beds, mangroves and coral reefs, all susceptible to small changes in sea temperature and climate; and which will be susceptible to impacts from cage culture operations; from higher dissolved nutrient loads to smothering from particulate loads, to damage during cage farm set up and operations, from boat traffic and general lack of care and attention.

The long term viability of the Red Sea as a whole relies upon maintaining these ecosystems in a good condition and not impacting the natural state through poor design, implementation and operation of cage culture operations.

When selecting a site it is important that maps, GIS databases and other resources are used to gain an understanding of areas which contain these important features and to select zones and / or sites that do not impact them.

5.4 FAD (Fish Aggregating Device) phenomenon

Similar to any other permanent or semi-permanent structure in the sea, fish farms may act as systems around which fish aggregate (Figure 34). This can occur for a number of reasons:

- The cages and nets can act as a safe-haven for fish which like the protection that structures in the sea give.
- Floating collars, nets, anchor lines and anchors and any other equipment and infrastructure below the waterline provide a surface on which to settle (collectively called fouling). Species might include microalgae, bivalves, corals, nudibranchs, sponges, bryozoans, barnacles and many other sessile species, which in turn can be fed on other fish species, for example.
- A certain level of feed is wasted and enters the environment around fish farms, and wild fish will be attracted to and will feed on this. This in turn attracts predators and other species, so that a mini-ecosystem might be developed.
- Dissolved nutrient levels around fish farms may increase, which can increase phytoplankton productivity locally (although not necessarily to high levels or bloom conditions), with a commensurate increase in zooplankton. This may attract species that feed on plankton.

As a FAD, attracting fish can have positive effects for the fish farm, by reducing the impacts from feed and faecal wastes for example with wild fish eating waste materials and reducing impacts on the seabed, or by reducing the amount of fouling on nets and other infrastructure. There are, however, also negative impacts, most importantly the attraction of predators, which may then attack nets to gain access to the fish stock.

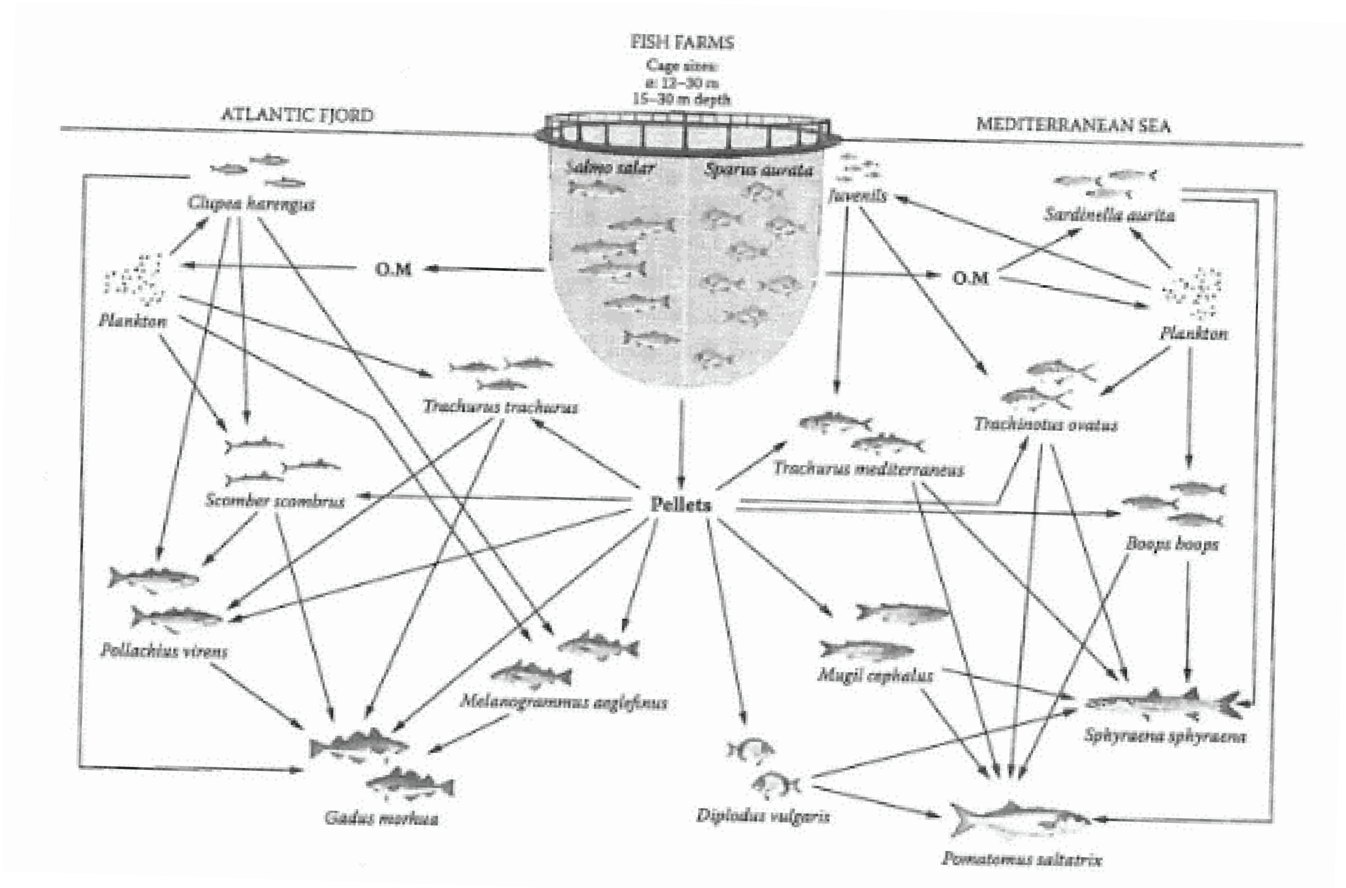

FIGURE 34: REPRESENTATION OF FISH FARMS AS A FISH AGGREGATION DEVICES[14]. MAY ATTRACT ECONOMICALLY IMPORTANT FISH, THOSE THAT ARE NOT ECONOMICALLY IMPORTANT OR THOSE THAT MAY ACT AS PREDATORS TO THE CULTURED FISH (AFTER SANCHEZ-JEREZ ET AL, 2011).

In terms of site selection, and as a precautionary measure, it is recommended that all cage nets are double-netted (a larger net outside the net that contains the cultured fish stock) as a means to lower the risk of the net being attacked and damaged, reducing incidence of wild predatory fish gaining entry to the main net, and as a measure to prevent cultured fish escaping.

It is unlikely that the wild fish at the fish farm site could be fished commercially, unless by rod and line, as trawling and other forms of netting are liable to tangle with the cage infrastructure.

14 Source: Sanchez-Jerez et al 2011, available at http://www.nina.no/archive/nina/PppBasePdf/Kapitler/2011/Uglem%20Coastal%20fish%20farms%20 p.187-208%20Artificial%20reefs%20in%20fisheries%20management%202011.pdf

6. Other considerations in siting aquaculture facilities

In siting an aquaculture facility at sea there are a number of other considerations that need to be taken into account in the choice of site, related to:

1) Minimizing conflicts with other users;

2) Avoiding areas that are designated for other uses or are otherwise off-limits;

3) Selecting areas that are readily accessible for the company, in terms of putting infrastructure into the sea, and transporting goods, services and people to and from the cage site as required; and

4) Access to facilities and infrastructure on land.

This section deals in broad terms with some of these issues. In site selection some of these issues may, be the single factor that means a proposed cage site is not selectable, even when all other conditions are favorable.

6.1 Minimizing conflicts with other users

Aquaculture in coastal areas can co-exist happily with other users of the marine environment, possible conflicts with people legitimately conducting fishing and sport fishing, transport of goods, bunkering, tourism and diving tourism and others that are visible uses of the marine environment and may be taking place in areas that are also suitable for aquaculture.

It must therefore also assess the presence of other stakeholders, such as:

Fisheries communities

Conflicts with the fishery can arise mainly for space competition. There could be areas traditionally exploited by local fishermen communities that might be suitable for aquaculture, leading to competing usage and need for compromise. Ideally by limiting the access in traditional fishing areas to fishermen only will limit quarrels and clashes between fishery sector and farmers.

Proximity to Touristic areas

Although tourism is not fully developed on the red sea coastline, and tourist areas are mainly represented by residential districts for seasonal holydays near large urban zones, interactions with aquaculture can generate conflicts and outcry against the farm facilities, both in land and on the sea. The Site selection study must take into consideration this aspect and analyse the tourist sector in the area.

Proximity to on-shore Aquaculture activities

Background bacterial levels can increase around fish cages and water quality can also be affected locally and could cause problems for farms that are using this water supply. Therefore fish cage licence should be located an appropriate distance from water intakes. A buffer zone should be required also between cage farm licences, and between cage farm licence and inland aquaculture facility outlets.

Other Industrial activities

The discharges and the outlets coming from heavily industrialized areas may lead to a deterioration of water quality.

6.2 Designated or restricted areas

Certain designated or restricted areas might not be immediately apparent and could include, for example, underwater cable lines, whilst others will be obvious such as ship anchorage (bunkering) areas. Maps (Figure 35) and GIS databases provide the best option for checking restrictions within the planned area, so that they can be avoided for consideration to site aquaculture facilities. A buffer zone between the edges of the designated or restricted area should also be applied. Buffer distance may vary, but should probably be a minimum of 1km to provide some flexibility to other water users.

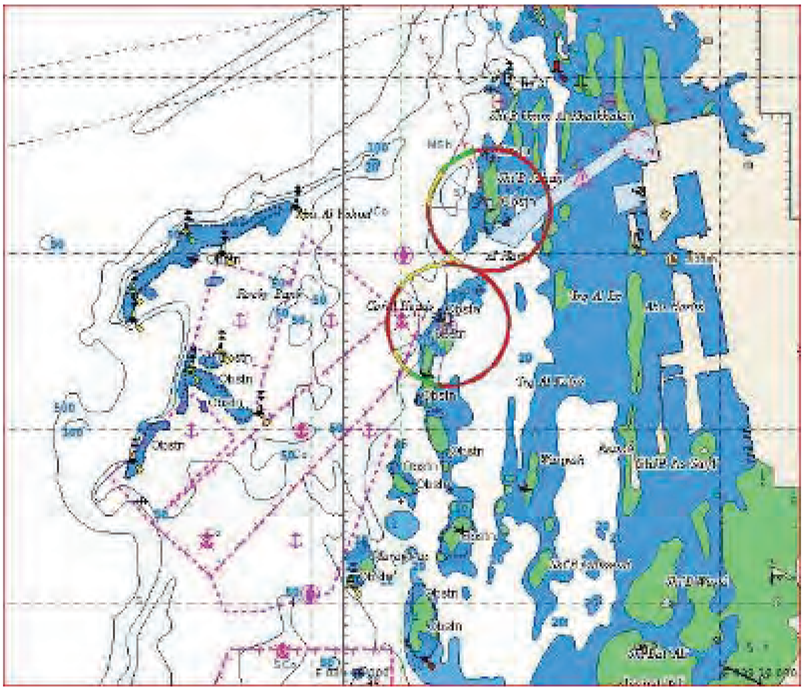

FIGURE 35: EXEMPLE OF MARINE RESTRICTED AREAS ON THE NAUTICAL MAP

Special restricted areas

Such as areas of archaeological interest must be avoided, as ruins or other finds can be damaged by mooring underwater or by constructions on the land.

Protected areas such as natural parks or heritage sites are to be avoided to reduce any kind of threats for the protected areas.

Dumping points and underwater outlets along the coast must be avoided and licence area must be located with a distance of at least 1 km from these points

Areas with underwater cables or conduits must be highlighted on the project map and no moorings or cages deployed that might interfere with the cables/conduits.

Regulated navigation area

Vessel anchorage areas are often located in the vicinity of harbours, straits or industrial areas and may be allocated for container ships and other transport vessels, including oil bunkering. Used as a stand by anchorage for managing the traffic flow and for the vessels intending to wait at the anchor. Areas are usually indicated on marine charts and cannot be occupied by aquaculture cage farms. Such areas present clear collision hazard.

Navigation routes or shipping lanes for larger boats (oil tanker, cruise ship, cargo ship, etc.) will also be indicated on maps, and also present a collision hazard. Navigation routes plus the buffer zone should separate cages sites from these routes. If near to a shipping lane or regular boat route it is recommended that cage sites are fitted with navigation lights, to make them visible at night. A further reason to avoid such areas is that large vessels passing through marked navigation routes can disturb fish production in terms of the waves created by the vessels and from underwater engine and propeller noise, which can cause stress in the fish.

Military protected areas

Any area designated as a military zone or military protected area mustnot be selected as a potential site. There could be zones interdicted to navigation or shooting range sea areas where the cage aquaculture activity cannot be developed.

6.3 Daily access to sea

Daily access to sea is a critical and necessary requirement for cage culture sites and restrictions on access for the specific aquaculture activity should not be considered or implemented. There are a number of critical management activities that requires this daily access, where:

- Fish need to be fed;
- Stock need to be evaluated for health and welfare;
- Repairs and general maintenance activity needs to be completed;
- Net need to be changed occasionally;
- Security of the site needs to be checked and evaluated; and
- General sea-based management needs to be carried out.

In addition, emergency access is also needed to ensure that repairs can be carried out in the event that damage occurs from wind and wave action, collision, predator attack or malicious damage. Other potential needs include recovery of escaped fish, when it is usual to attempt to recapture a mass escape of stock through a combination of feed addition outside the cage and seine netting to avoid ecological damage through escapes.

Periodic activity is also critical, as cages, moorings and other infrastructure need to be deployed initially, replacements deployed when needed; or when fry are transported to site and harvested fish are transported from sea to land at harvest time.

When sites are a long distance from shore the costs of daily transport in fuel costs and lost efficiency in staff (who are spending time travelling and not working), and of conducting the activity above can alter the profitability and economic sustainability of the operations. There is therefore a balance needed between distance to shore to provide the environmental conditions needed to grow fish and maintain infrastructure, and the need to visit the site on a daily basis for those regular activities and on other occasions for those unexpected or more irregular activities.

Distance from shore is a consideration for the company concerned when selecting their site, who must balance the positive environmental benefits of being further out, against the economic realities of being this far off shore, to ensure both environmental and economic sustainability.

6.4 Access to infrastructure on land

As well as environmental and management issues related to distance from shore when selecting a fish farm site, there are other parameters where distance from site is also a consideration, in particular:

- Proximity of harbour / jetty / marina for boat anchorage, staff and equipment loading and unloading;
- Proximity to shore base offices and storage facilities for feed, equipment and staff offices;
- Access to roads for transport;
- Access to processing facilities, where these are not locally integrated;
- Electricity and potable water supply services;
- Proximity to the market, for local sale;
- Proximity to main airport / ports, for exports;

The first two parameters are often the same location, and within the KSA where there may not be sufficient harbours / jetties / marinas available for boat anchorage, and loading and unloading activity then companies may be required to build these facilities and it would be logical to build the shorebase (storage / offices / other facilities) as an integrated part of that development. Note that selection of sites for shore facilities, and applications for shore-based infrastructure requires a separate application to the Municipality. It is recommended that selection of shore bases goes ahead in parallel to any cage site selection activity.

(Footnotes)

1 Magill et al 2006, available at http://www.sciencedirect.com/science/article/pii/S0044848605003893

GUIDELINES AND CRITERIA

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