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It is important that these efforts be combined with those for the prudent conservation and development of our water resources. They must be regarded as our national wealth and be used economically.

His Majesty Sultan Qaboos bin Said
Foreword

The development of an active aquaculture industry in the Sultanate of Oman will provide new business and employment opportunities. As well, aquaculture will supply healthful and safe seafood products for Omani consumers and an additional source of export income for the national economy. Before expansion into a new production sector however, its environmental and economic sustainability must be assessed. With this in mind the Ministry of Agriculture & Fisheries Wealth commissioned two missions by the FAO to examine the present status and growth potential for aquaculture development in the Sultanate.(1),(2) Clear from both reports was that aquaculture has substantial prospects for expansion provided that this is undertaken with environmental diligence. A critical step in this direction was recognition by the Ministry of Agriculture & Fisheries Wealth that Environmental Better Management Practice (BMPs) guidelines were needed in order to support industry development while providing an environmental template for the construction of comprehensive production plans.

BMPs unify generally accepted production methods with guidance on how to improve long-term efficiency and environmental durability. BMPs are a voluntary set of minimum standards that assist in decision-making processes while fostering acceptance of new industries by stakeholders who share or compete for neighbouring resources and space. An obligation of aquaculture producers should be to incorporate BMPs into each stage of the production plan since they offer a flexible alternative to more restrictive, enforced legislation. By their nature BMPs enhance the safety of farmed foods and provide regulatory authorities information necessary to exempt farmers from policies that may be in place for wild-caught species. BMPs will also provide administrative agencies with a means of verifying compliance to rules that govern issuance of certification for exceptional products, such as ecolabels and organic certification.

This document provides a list of guidelines or BMPs to ensure that aquaculture development occurs with due respect for Oman’s heritage, culture and environment. The BMPs approach does not provide directives but offers a range of options that may be used by producers for site-specific conditions. Because of the diverse nature of aquaculture there is often a need to supplement general principles of guidance with more specific BMPs that apply to a particular species or system of culture. Supplementary BMPs are thus presented as appendices that cover the most likely forms of aquaculture that will be practiced in Oman in the immediate future: pond cultivation of marine shrimp, cage or net pen culture of finfish and cultivation of marine molluscs. As alternative species or systems become more prominent, additional guidelines will be developed. Indeed the underlying principle of the BMPs approach is flexibility to allow infusion of new ideas to enhance environmental wellbeing and sustainable growth. As fresh scientific information, production concepts and technologies emerge there will be a parallel evolution in BMPs that will necessitate the timely up-dating of this manual.

It is important that the user of this manual realizes that many legal regulations govern the operation of aquaculture facilities in Oman and these must all be taken into account during planning and operation of new farms. Provided that all national legislation relating to aquaculture and the principles outlined in this manual are respected, then the nation can anticipate the development of a region-leading sustainable enterprise.

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Muscat, March, 2010

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1.0 Introduction

“States should consider aquaculture, including culture-based fisheries, as a means to promote diversification of income and diet. In doing so, States should ensure that resources are used responsibly and adverse impacts on the environment and on local communities are minimized.”

Article 6.19, General Principles
Code of Conduct for Responsible Fisheries

Like other forms of farming the profitability of aquaculture is dependent on making sure that stocked animals or plants are healthy and reared in an environment optimized for their growth. It is within the better interests of the farmer therefore, to ensure that the living environment of stocked organisms is likewise healthy. The application of BMPs can assist in achieving this goal by helping to foster successful enterprise without negative environmental impact. BMPs unite legislative and regulated mandates with generally accepted production practices to ensure the long-term efficiency of a business while helping achieve the goal of sustainability and allowing producers to become established and valued members of their local communities.

Strict observance of BMPs helps to prevent conflicts with neighbours and other users of common resources while ensuring also food safety. The latter has become of increasing public concern following contamination of a growing variety of foods with chemicals (antibiotics and melamine) and viral particles (e.g., BSE, SARS, swine and avian ‘flu). The use of BMPs as a method for achieving environmental protection and conservation and for sustaining biodiversity, as an alternative to more rigorous legislation, has been supported by governments, private and non-governmental organizations and producer groups throughout the world since the late 1980s. BMPs play a core role in countries attaining the goals set forth by the Food and Agriculture Organization’s Code of Conduct for Responsible Fisheries(1) and similar documents, such as those prepared by GESAMP.(2)

1.1 Ecocentrism or Technocentrism?

The business of aquaculture may have wide-ranging impacts on the environment and methods for increasing the sector’s overall ecological performance can be approached using different spatial scaling(3). These may range from the manageable (individual production units) to the less controllable (the biosphere). The ecocentric approach to sustainability concentrates on ecosystem preservation, using fundamental changes in societal values and existence, and minimization of resource use. Ecocentric approaches tend to consider large spatial scales. On the contrary, technocentrism considers ecosystem conservation, technology development and improvements in the efficiency of resource use(4).

Technocentric approaches tend to provide solutions to environmental problems that are more local and thus on smaller spatial scales. The technocentric method therefore, generally provides more rapid solutions to localized problems while ecocentrism reflects on sustainability in the global context.

Both concepts provide structured and logical frameworks to attaining the goal of ensuring that actions of today do not compromise the well-being of future generations. To attain sustainability objectives for aquaculture, both eco- and technocentric viewpoints must ultimately be addressed.

To the individual farmer the goals of the ecocentric model might appear lofty and unattainable, but decisions made by farmers relating to resource use and modification can champion the ecocentric cause. Nevertheless, because humans have an innate understanding and feel for local spatial conditions, they inevitably have greater confidence in the technocentric approach to sustainability. Indeed, most aquaculture BMPs are biased towards technology implementation and the more efficient use of resources. These methods generally have more rapid and discernable effects and are thus normally favoured by producers.

1.2 Aquaculture interactions

The aquaculture sector supports the activities of, and interacts with, a wide variety of stakeholder and other groups (Fig. 1.1). These include subsidiary industries that rely on aquaculture as a customer for products and services, through to individuals who might be affected by the immediate activities of a production unit. For example artisanal fishers may be hampered by new navigational problems or accessibility to launch sites. On the other hand, a new industry can bring with it new employment options for local communities as illustrated by individuals engaged in larvae and broodstock collection during the early phases of new species culture, or womenfolk and others occupied by the processing and sales sectors. It is clearly important, wherever possible, that members of impacted groups are considered in the development of BMPs. This ensures harmony between stakeholders and provides a degree of transparency in the process of evolving guidelines that are acceptable and fair to all parties. Ultimately however, the responsibility of formulating and drafting BMPs for aquaculture should be undertaken by technical experts. The brief of these experts should be to address all critical BMP issues while ensuring their practicality, effectiveness and tolerability by all those concerned. Moreover, it is essential that adopted BMPs are verifiable so that when incorporated into certification programs, their implementation can be independently assessed.

1.3 Using BMPs

A general rule of thumb in developing BMPs has been to identify areas that may have potential environmental impact and to present a range of options for solving problems using a category by category approach. Adoption of this type of strategy has been widespread. The voluntary set of standards and procedures included in this manual are intended to help aquaculturists improve production methods in the Sultanate of Oman while avoiding negative environmental and social impacts.

BMPs should form an integrated component of all planning and operation phases of aquaculture production both by individuals and companies who wish to start a new aquaculture venture as well as by those contemplating expansion or modification of existing facilities. BMPs can also be employed by existing aquafarmers to identify critical areas of production that may require improvement to optimize environmental and social sustainability. The BMPs contained in this manual can also be used as a template for farm managers to construct Standard Operating Procedures (SOPs). Carefully constructed SOPs are useful because they encourage managerial and operational efficiency and can assist during employee training to highlight environmental protection, resource use options and social responsibility.
Figure 1.1 Aquaculture supports a wide variety of subsidiary industries and activities, the most important of which are exemplified in this diagram. By interacting with so many different sectors, aquaculture has the potential to have near and far-ranging environmental impacts.
Figure 2.1 Map of Oman illustrating principal coastal substrate types major bird havens, turtle nesting and feeding areas and large mammal reserves. Territorial waters extend 12 nautical miles seaward while the exclusive economic zone extends 200 nautical miles seaward. (1)

1.4 Limitations of BMPs

It is important to understand that BMPs do not act to reduce a particular impact uniformly, even when farmers are growing the same species in a similar location. The effectiveness of BMPs are dependent on numerous interrelated factors: species and genetic line cultured, scale of production, management system employed, water quality and volume available, previous experience of producers and staff, feed used and so on. Moreover, simple adoption of BMPs will not always result in an acceptable improvement in a farm's environmental performance. These are two reasons why BMPs should be considered as flexible solutions rather than mandated procedures and why producers should anticipate regular updates and modifications to developed guidelines. A major industry assumption with respect to adoption of BMPs has been that their implementation produces measurable benefit and assures regulatory compliance. While these assumptions are often correct, this is not always true and it is, therefore, essential that the performance of BMPs-based programs can be verified in a quantitative manner by the producer, regulatory agency and/or independent assessor.

The quantitative assessment of the cumulative beneficial effects of BMPs on environmental quality and industry sustainability provides a means of benchmarking. This form of standardization may be used to identify and differentiate poor and superior producers. The quantitative measurement of BMPs performance can, therefore, be of use throughout a product chain. Producers may benefit through increased efficiency and hence profitability; seafood buyers recognize that BMPs implementation indicates higher quality products; regulatory agencies view functional BMPs as a means of establishing compliance and satisfying labeling requirements; investors perceive compliance as reducing risk and consumers identify their implementation as being environmentally and socially friendly.

The thorough adoption of BMPs by producers is often dependent on the costs associated with implementation and on technical and operational feasibility. Costs connected with implementing BMPs include the capital needed to invest in and install new structures and/or equipment; additional outlays required to operate and maintain a facility with BMPs in place; and the costs associated with monitoring, reporting and inspection. When the price of implementing a series of BMPs is too high then a producer will not voluntarily adopt such practices. If BMPs are mandated however, their uptake may cause the business to fail. This is an important reason why the formulation of BMPs must be entrusted to technical experts who are better equipped to assess practicalities, BMPs effectiveness and their economic tolerability. Often, special interest groups, for whatever reason, remain oblivious to such constraints and rarely, if ever, offer up sensible alternatives.

Non-economic factors may also hinder uptake of BMPs. Farmers may consider specific BMPs technically too complex, incompatible with their operation, or unlikely to improve upon existing production strategies.

2.0 Manual layout and content

The template for the following manual has been structured and arranged in accordance to published recommendations made by a wide variety of individuals, agencies and organizations. These include environmental protection organizations, producer and consumer groups, government bureaus, and other public and private associations and stakeholder committees. The goal of this manual is to ensure environmental and social sustainability of aquaculture in the Sultanate of Oman. In developing BMPs for Omani aquaculture therefore, prevailing geographical and climatic conditions of the nation have been taken into consideration. Adoption of this position limits the simple incorporation of existing BMPs into the manual because these have generally been written for temperate and tropical
geographies. For example, in a country where annual precipitation is less than 125 mm\(^{(1)}\) it would be foolish to recommend the use of grass to stabilize pond embankments and levees and trees to enhance the aesthetics of a site. Likewise, prevailing soil types will oftentimes be cohesionless in Oman and thus demand the use of liners and other methods to modify consistency. Other unique issues exist in the Sultanate and, wherever possible and practical, these have been considered and incorporated into the manual. It is hoped that this document will, therefore, be of relevance and help to other countries that possess similar geographies and climates.

In developing BMPs for Omani aquaculture various categories of environmental impact have been identified and a range of options offered to address specific impacts under each grouping. For utility, this manual has been divided into two sections. The first provides BMPs considered as being universal to all production systems, commencing with deliberation of site selection and ending with BMPs for facility operation and maintenance. Because aquaculture is so varied in scope, an appendix section has been incorporated to account for BMPs that are appropriate to specific culture environments. Explicitly, sections have been provided on BMPs for cage culture, marine shrimp farming and the cultivation of shellfish. Together with others, a section on occupational and community health and safety is included. Inevitably, some management practices will be duplicated across sections. This replication highlights the interconnected nature of BMPs and the potential for the occurrence of cumulative beneficial effects with full implementation.

3.0 Site selection and facility construction

The first step in the construction of an aquaculture facility is the identification of an appropriate site. Indeed, incorrect decisions at this primary planning stage can determine success or failure of a new operation. Several factors influence the selection process for culture sites and although some of these are obvious (e.g., water supply and quality), others may be less so (e.g., ensuring historical land or beach access). Any construction has the potential to incur far-reaching and significant negative impacts on the environment which include increasing the prospects for erosion, negative impacts on local hydrology and water quality and harmful effects on sensitive habitats and ecosystem functions. The aquaculture literature is littered with examples of poor facility siting resulting in operational failure, environmental catastrophe and social injustice. In the Sultanate several regions that may be considered appropriate for aquaculture have already been designated as environmentally sensitive or of value for other reasons (Fig. 2.1). Aquaculture activity in these areas is therefore, precluded. Examples include nature reserves as exemplified by the Khawrs of the Dhofar coast, the Dimaaniyat Islands, Jiddat al-Harasis and Ra’s al Hadd and areas considered of importance to tourism and national heritage. On the other hand, the Ministry of Agriculture & Fisheries Wealth has conducted a number of site surveys and pilot-scale production studies with several species and these efforts have led to the identification of several environmentally suitable locations for aquaculture permitting.

3.1 Basic considerations for site selection

Assessment of a potential site for aquaculture should take into account its previous history of use in order to avoid existing soil pollutants contaminating farmed animals. The region surrounding the site should also be examined for land-based sources of pollutants including both point and non-point inputs, and assessors should venture to project the position of present and potential future aquaculture sites and sea and land disposal areas. Selected sites should be well drained and above the 100-year

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flood mark,\(^{(1)}\) exhibit a topography suitable for the proposed operation,\(^{(2)}\) contain soil types that are fitting for ponds, if these are to be used, and have access to a sufficient and acceptable water supply.

The site should exhibit conditions that are favourable to effluent management (disposal or dispersal), provide an appropriate climate (temperature, rainfall, winds, cloud cover) for the species cultured, have year-round market access and express suitable shape and size to allow for future expansion. Ideally, chosen sites should have access to uninterrupted electrical supply, good communication systems\(^{(3)}\) and permit ready contact with technical expertise when necessary. The proximity of the site to hatcheries, fingerling suppliers, feed manufacturers, processors and a skilled workforce may also enter into site selection criteria. Siting of cage aquaculture and marine shellfish operations should incorporate assessment of tidal flux, currents, coastal fetch, primary productivity, and potential for cage, rope and shell fouling.

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\(^{(1)}\) Shifts in global and regional climate have resulted in increased flooding of areas that previously appeared protected from such events. While impossible to predict the severity of future floods in specific coastal areas, sites should take account of rising sea levels and changes in oceanographic processes that may accompany alterations in prevailing climate. Recent tropical cyclone experience highlights the importance of site selection with respect to positioning of facilities away from wadis.

\(^{(2)}\) Natural landscape contours can be used to conceal facilities, thereby reducing aesthetic impacts on the environment.

\(^{(3)}\) Existing infrastructure minimizes landscape change caused by lying of roads, tracks, electric lines etc.
3.2 BMPs for site development

After a decision has been made that a specific site may be appropriate for the planned aquaculture operation, the following guidelines should be adhered to:

1. Ensure that all required certifications and permits are obtained prior to any physical site preparation and or construction.
2. Comply with all regulations regarding zoning, construction and earth removal.
3. Maintain supporting documentation substantiating the above for organized and spot inspections.
4. Do not position facilities near protected areas and ensure that migratory bird sites and wildlife corridors and sanctuaries remain uninterrupted and undisturbed (see Fig. 2.1).
5. Do not convert productive agricultural lands into aquaculture operations.
6. Select sites that have suitable water supplies that are free from contaminants.
7. Reject sites that are prone to flooding or extremely inclement weather conditions (see note 6).
8. Select sites where natural drainage and run-off patterns can be incorporated into overall facility design.
9. Pick locations that require the least amount of earth moving during construction and minimize any modifications to terrain during construction.
10. For pond-based methods make sure soil type is suitable for construction (see Fig. 3.1 and note 16). In some areas of the Sultanate apparently sandy soils can be employed for levee construction due to the presence of gypsum which acts as a natural binder.
11. Choose sites that are appropriately shaped and sized for future facility expansion.
12. Confirm that construction activities do not cause offsite silting or heighten the probability of flooding or sand drifting.
13. Use cut-and-fill methods for pond constructions wherever possible to decrease major changes in site landscape.
14. Make sure that marine pond bottoms and embankments are well compacted or that appropriate liners are used to minimize potential salinization of ground water supplies.
15. Make certain that imported fill materials are clean and free of debris, waste and contaminants.
16. Store moved site soils to assist later coverage of banks and liners.
17. Scarify land where levees are to be constructed to ensure good bonding between base soil and embankment materials.
18. Rapidly stabilize disturbed soils to prevent erosion.
19. When soils lack cohesion, such as highly sandy soil, utilize clay mixtures or other stabilizers for top dressing. For smaller areas, sandy soils can be stabilized using a variety of commercially available products.
20. Remove and relocate objects (stumps, large rocks) that may puncture liners or impede harvest activities or cause safety hazards during site operation.
22. Make sure that facilities do not impede or change historical access points. Oftentimes access to beach areas may be seasonal.
23. In discovering artefacts or potential sites of cultural or historical importance immediately stop

(1) This may be an extremely important consideration in some areas of the Sultanate which is prone to flash flooding from seasonal rainfall and monsoon events.
(2) The general suitability of specific soils and sites should be confirmed using soil test pits sunk at various areas of the site (see Fig. 3.1). Soil test pits can be used to establish texture and grain size characteristics, and depth of the impervious layer as well as historic site use.
(3) Examples of sandy soil stabilizers include various liquid polymers, plastic composites and cloths.
(4) It is sometimes necessary to employ herbicides for plant removal, liming for soil pH adjustment and so forth. When applied ensure that all chemicals are used in agreement with applicable national regulations and in accordance to the manufacturer’s instructions.
all activities and inform the Ministry of Heritage and Culture and interested parties such as the Historical Association of Oman.

24. Provide buffer zones around the facility to reduce noise impact and where applicable use barriers to reduce noise (e.g., from generators).

25. Place intakes and discharge lines in locations to eliminate environmental impacts.

26. Use gravel to stabilize roads and facility access points and walk and driveways\(^{(1)}\).

27. Whenever possible take aesthetics into consideration by using natural topography of the land to conceal the site or components thereof.

28. For chemical and fuel storage areas ensure placement of protective berms and liners around storage containers and areas. Fuel and chemical storage sites should be placed at least 50 m downslope from any natural source of spring or well water.

### 3.3 Soil test pits

Thorough soil analysis should be undertaken immediately on identifying a potential site since soil quality can rapidly provide decisions on site suitability for aquaculture. A variety of manuals are available to assist in the soil testing process\(^{(2)}\). Generally, a site's soil characteristics are examined using soil test pits (Fig. 3.1).

> **Figure 3.1 The suitability of a site’s soil type can be established using soil test pits. These should be dug at various parts of the proposed site to take account of variations in soil quality as well as to obtain an indication of previous site use history. Soil cores should be collected from the surface, 0.5 m and below proposed pond bed in cut-based ponds.**

(1) This reduces the degree of environmental dusting and general erosion caused by heavy traffic.

These, usually 1.5 - 2.0 m deep, stepped excavations, allow assessment of variations in soil quality at different depths using soil cores. Measurements generally made include soil texture (see Fig. 3.2) or grain size distribution, soil consistency or plasticity, compaction rating, and particle settlement analyses. pH, organic matter content if present, percolation rate (the coefficient of hydraulic permeability), soil microbe make-up and presence of pollutants are also examined during soil tests. These relatively fast and inexpensive investigations can provide an immediate indication of potential impact for example, that might be caused by seepage and an indication of the possible negative effect of site use on salinization processes.

*Figure 3.2* Sandy and cohesionless soils may require use of imported soils for amalgam purposes to enhance structural solidity. Alternatively, barrier materials including plastic liners (left photograph) of various thicknesses and cloth-like liners (right photograph) are commercially available to provide structural stability to the sides of levees.
4.0 Water, effluent and solids management

Commercial aquaculture operations use a variety of production systems and each bring with them different problems and solutions to managing water resources, effluents and solid wastes. Water quality and quantity represent key considerations during site selection and it may be necessary to pre-treat water supplies. In the Sultanate of Oman the use of sweet water for aquaculture will be largely restricted due to the lack and competing use of freshwater springs and wells. Nonetheless, when employed during aquaculture the efficiency of potentially potable water supplies should be optimized by reducing exchange rates, and through recapture and reuse, for example for crop irrigation purposes and animal watering. Ponds have two distinct types of effluents: overflows following rainfall and flooding (unintentional water exchange) and deliberate water discharge during pond flushing and drainage as seen during harvesting. In Oman, overflows due to excessive rainfall will occur only rarely whereas those resulting due to flooding may, over time, increase in incidence due to global climate change. Effluent quality from unintentional pond emissions is generally higher than that encountered following intentional water drainage due to dilution effects. Nevertheless, both types of overflow water can contain solid and or particulate materials including phytoplankton-based detritus, soil particles derived from embankments and pond bottoms, and wastes from feeds and animals. Displaced pond water, whether fresh or brackish, therefore, is considered a pollution load to the environment and, when intentionally released, may also represent energy waste from pumping activities.

The major components of solids in aquaculture are uneaten feed and faecal matter. Solid waste build up is problematic not only in environmental terms but also during production. Solids irritate gills, cause water column oxygen depletion due to decomposition, and provide a potential habitat for pathogens. Because a proportion of fish waste contains excreted and undigested nitrogen (N) and phosphorus (P), solids also contribute to their environmental loading. A recent innovation in cage siting and environmental management has been the application of computer modelling to discern the dynamics of N and P and their dissolution. A general rule of thumb for solids removal is that the smaller the particle sizes the more difficult, and generally expensive, to handle and treat. Therefore, when necessary or feasible, solids capture and elimination should be undertaken as rapidly as possible. A number of treatment technologies for solids removal are available but these will likely have limited application in the Sultanate outside their use in recirculation systems.

4.1 BMPs for water, overflow effluents, and solids

To ensure against negative environmental impacts associated with water, effluents and solids:

1. Comply with all applicable effluent standards.
2. Site the facility away from areas prone to flooding (e.g., wadis) or severe weather events.
3. Make sure that pond capacity is large enough to handle additional water inputs due to flash flooding and similar events.
4. Ensure that pond construction is of high quality using appropriate soils, liner materials and compaction practices.
5. Design all pond drainage systems to be able to handle overflows from severe weather (drainage pipes should be of 20 cm diameter or greater).
6. Position drains to avoid erosion and blockage of embankments and trenches.
7. During construction orientate ponds with due regard for wind direction and speed and size of ponds to minimize wave action and associated scouring.
8. Increase hydraulic retention times to enhance in-pond elimination of N and P and organic build-up thereby managing ponds to their assimilative capacity.
9. Do not drain ponds that have freshly received fertilizers or chemical treatments.
10. Prevent water discharges following disease events.
11. During harvesting, rather than draining, reuse or recirculate water into adjacent ponds.
12. Allow solids to settle before discharge. After harvesting, leave residual water in ponds for 3+ days to permit nutrient use by phytoplankton.
13. Where permissible construct settling ponds to pre-treat water before discharge into coastal areas.\(^{(1)}\)
14. If siting permits allow construction of artificial mangrove wetlands, use these as biological filters.\(^{(2)}\)
15. Avoid discharging into areas close to coralline areas.
16. When fresh or slightly saline (< 2 ‰) waters are discharged use for crop irrigation and animal watering.
17. Monitor off-site water quality to establish whether effluents have negative impacts.\(^{(3)}\)
18. Deploy appropriate water treatment technologies in recirculating systems (RAS) to remove solids.
19. In RAS use UV and ozonation technology to destroy pathogens before water discharge.
20. Combine freshwater RAS systems with plant irrigation.
21. When feasible, dewater collected solids from freshwater RAS and use as fertilizer and for land stabilization.
22. Employ RAS solids as a medium for vermiculture and for the production of composts (Fig. 4.1).
23. Use sediments from settling ponds for polyculture of detritivores and macrophytes for nutrient recovery. Polyculture may also reduce disease outbreaks.\(^{(4)}\)
24. Continuously scrutinize, adjust and improve management actions intended to reduce water and effluent discharges.

\(\text{Figure 4.1 When freshwater recirculating aquaculture systems are employed, dewatered solids can be recycled as media for vermiculture and for compost production. Nutrient recapture can be attained from marine effluents through cultivation of Nereid worms. Images courtesy Dr. L. Marsh, Virginia Polytechnic Institute and State University and Dr. S. Craig, SeaBait Ltd., UK.}\)

\(^{(1)}\) Settlement ponds can potentially be used to recoup nutrients by producing detritivorous species such as sea cucumbers and Nereid worms. The latter may provide an alternative source of feed protein but field trials must be undertaken to ascertain the potential of these methods.


\(^{(4)}\) Tendencia, E.A., 2007. Polyculture of green mussels, brown mussels and oysters with shrimp control luminous bacterial diseases in simulated culture system. Aquaculture, 272, 188191-.
5.0 Feeds and feeding

The main aim of aquaculture is to manage water bodies to produce more aquatic animals or plants per unit volume than would occur without intervention. With the exception of shellfish culture, this is enabled by introducing concentrated energy into the culture environment. Depending on the intensity of production and species farmed, two main methods are employed to provide food in aquaculture settings: fertilization to increase the natural productivity of ponds, and formulated diets. In certain cases, both feed types are exploited during production and in hatcheries, and especially those for marine carnivorous species, live feeds (algae, rotifers, copepods, Artemia etc.) and specialized weaning diets are employed. Fertilizers, formulated diets, and live feeds used in aquaculture all have negative environmental impacts since energy and resources are diverted from one environment and directed into another. Over 40% of global aquaculture is dependent on the use of formulated feeds. The technical manufacture of aquafeeds tries to take account of all the cultured organism’s micro- and macro-nutrient requirements. In doing this, growth and animal health performance is maximized while waste production is minimized.

The composition of commercial aquafeeds may vary considerably due to the application of least-cost diet formulation methods. Most feeds will contain a variety of animal and plant-derived protein and lipid sources together with vitamins, minerals and binders. The protein component of aquafeeds, representing approximately 55% of its price, is the most costly ingredient. The feed manufacturing industry have thus invested in developing feeds that reduce protein costs by using less expensive sources. These include diets that employ plant proteins such as soybean meals and concentrates as well as rendered animal and bloodmeal products. Dangers inherent with the use of the latter two alternative protein sources include the potential for disease transference. Because P is in the form of phytate in plants and is therefore unavailable, additional P must be added to aquafeeds to meet requirements, leading to increased environmental P loading in effluents.

5.1 Fishmeal use in aquafeeds

Because it is palatable and highly digestible and expresses excellent profiles of essential amino acids, the gold standard protein source for aquafeeds has been, and remains, fishmeal (FM). The utilization of FM in aquafeeds represents a major environmental concern because for some species no net increase in aquatic animal production accrues with its application. Even so, in 2006 aquaculture exploited 53% and 87% of global FM and fish oil production respectively. Placed into perspective and using an estimate of 4:1 conversion of fish to FM, a feed conversion of 1.2:1 with feed containing 35% protein, of which 50% is FM, reasonable conversion rates are nevertheless seen in intensive aquaculture. Indeed, some argue that conversion of fish into FM for aquafeeds results in superior conversion rates to those seen in nature (estimated at 10:1). While remaining a contentious issue,
use of FM in feeds has declined dramatically and for some species, its inclusion levels may only be 25%-.. Despite research showing that it is possible to remove all FM from diets, even for marine carnivores,(1) aquaculture persists in using FM and the ethical issues (feeding fish with fish) remain. BMPs for fish feed and feeding should include two categories: one for feed manufacturers and another for aquaculturists. Aquafeed BMPs may include issues such as feed formulation, ingredient selection, and assessment of manufacturing methods, warehousing and storage and others.(2) BMPs for feeds and feeding practices include issues such as the amount, frequency of feed delivery, pellet size, and the methods used to store, handle and distribute feeds. Optimal feed management practices substantially reduce environmental impact potential while also increasing a farm’s operational profitability.

5.2 BMPs for feeds and feeding

Strategies that decrease the environmental impact of feeds are broad ranging and to minimize negative effects, producers should:

1. Select sites that provide conditions that are optimized (e.g., temperature, salinity, water supply) for maximum efficiency of food utilization.
2. Use only the highest quality aquafeeds available.(3)
3. Never use raw fish or seafood as feeds.(4)
4. Ensure that all the feeding practices employed maximize the efficiency of feed use.(5)
5. Certify correct selection of feed based on nutritional requirements of cultured animal.
6. Use the manufacturer’s species- and feed-specific feed tables whenever available and applicable.
   A. Use life-cycle based diets with optimal feed sizes
   B. Calculate feed conversion efficiencies regularly (see Fig. 5.1), especially where feed tables deployed do not match animal performance
   C. Employ feeding methods that provide an even distribution of feed. This reduces the formation of feeding hierarchies that are oftentimes associated with feed wastage
   D. Train employees in correct feeding methods and to recognize changes in feeding activity (e.g., appetite) during production cycles and check employee consistency in feeding practices
7. Monitor feeding activities of stocked animals and employ appropriate seasonal adjustment in feeding times.(6)

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(3) High quality feeds have improved nutrient retention efficiency and thus reduce metabolic waste production. Well formulated feeds employ optimal balance of protein to energy to spare dietary protein, thereby increasing muscle growth and reducing nitrogen output. The available phosphorus levels should not be too high above dietary requirements in order to reduce environmental P loading. Good quality feeds also contain a lower level of fines or dust. Extruded rather than steam pelleted (sinking) feeds are more resilient in the water column and are therefore recommended.
(4) At present the availability of formulated, highly palatable feeds for broodstock diets is poor, especially for marine carnivorous fish. Hatcheries therefore, have the tendency to employ ‘wet’ diets consisting of squid, crab and oily fish. This appears to increase the quality (and quantity) of eggs produced. Use of wet diets should, nevertheless, be minimized and when employed extra caution maintained in treating effluents. The dangers of using wet diets from a disease transfer perspective should not be underestimated.
(5) Water quality can rapidly deteriorate when feeds are provided to excess resulting in localized hypernutrification and eutrophication of receiving waters. Aeration of ponds increases capacity to assimilate organic materials and higher DO is reflected in better nitrification and feeding rates.
(6) Direct observations are preferred over any other method since the feeder can also keep an eye on animal behaviour and health. In net pen operations, underwater cameras and pressure-based detection systems have been employed to control feeding durations whereas in tank-based systems, electronic feed shut-off mechanisms, located at tank outlets, have been used. Certain fish exhibit seasonal shifts in peak feeding activities and this should be taken into
8. Adjust pond feed application rates to prevailing temperature and whether aeration is used – this issue may be highly variable in the Sultanate of Oman.

9. Check for efficient operation and maintain equipment used for automatic feeding or feed dispersal.

10. Follow feed storage, handling and delivery methods that minimize waste and pellet disintegration.

11. When possible re-pellet fines and feed particles – use screens on feeding equipment for fines collection.

12. Keep feed storage areas secure, dry and free of all vermin.

13. Store a sub-sample of feed in a freezer to verify stated compositional analysis.

14. Keep accurate records of received feeds, copies of their labels, invoices and dates used. Maintain records for at least one full production cycle.

15. Use feeds on a first-in and first-out or rotational basis.

16. Never feed mouldy feeds since this can reduce animal feed conversion efficiencies.

17. Feeds should not be used past the manufacturer’s sell-by dates – usually 90 days in cold storage. This will be reduced substantially under Oman’s environmental conditions when refrigeration units are not employed.

18. Use and store medicated feeds according to the manufacturer’s instructions.

*Figure 5.1 Diagram summarizing the theoretical relationships between feed intake, fish growth and feed conversion efficiencies.*

5.3 BMPs for medicated feeds

When dealing with disease outbreaks it is often necessary to treat stocked animals with medicated feeds. It is important as part of an integrated health plan that the feeding of animals is monitored very carefully since one sign of an impending disease problem is a reduction in appetite. Since almost all anti-bacterial drugs are administered in feeds, inappetence will severely reduce chances of successful treatment.

1. Follow the guidelines for feed handling as prescribed in section 5.2.

2. Only use medicated feeds when this action has been approved by a qualified aquatic animal health account during production.
professional.
3. Use only nationally approved antibiotics for treating the diagnosed disease.
4. Determine resistance to any prescribed antimicrobial agent before application.
5. No reformulation of medicated feeds is permitted.
6. Be aware that appetite of diseased fish is usually reduced. Therefore, observe stock when feeding medicated foods and adjust rations according to feeding activity to reduce chances of antimicrobials accumulating in the environment.
7. Feed affected stock for the prescribed amount of time.
8. Make sure that treated stocks are identifiable and that withdrawal times recommended by the veterinarian are met before harvesting.
10. Store and use all medicated feeds in accordance with the manufacturer’s instructions.
11. Do not use out-of-date medicated feeds.
12. Keep complete and accurate records of medicated feed use, disposal, etc.
13. Dispose of left-over feeds according to national regulations.

5.4 Pond fertilization

In some production systems chemical and organic fertilizers, and their combinations, are employed to increase the natural productivity of ponds. Such strategies are seen in the culture of fish and crustaceans and especially during the cultivation of shrimp and certain fish larvae. Fertilizers deliver additional nutrients to ponds to stimulate natural production of phytoplankton and bacteria which serve at the base of food webs to provide increased abundance of natural prey items. The use of fertilization can represent a cost-effective means of enhancing productivity but, when applied inappropriately they can cause an environmental nightmare both within and outside the facility. In freshwaters, algal growth is usually limited by phosphorus whereas in brackish water, it is nitrogen that is generally limiting. It is important therefore to determine the limiting nutrient before choosing and applying fertilizers. This may be evaluated using algal bioassays.\(^{(1)}\)

5.5 BMPs for pond fertilization

1. Do not use fertilizers when ponds receive nutrient inputs from other sources.\(^{(2)}\)
2. Use assays and soil/water test kits to ensure efficient applications of fertilizers.
3. Plan the rate and method of application to maximize utilization and to prevent over-application.
4. Avoid using animal manures as fertilizers when these may contain antibiotics and other drugs that may contaminate the environment.
5. Increase efficiency of application and dispersion through practices such as using liquid fertilizers.
6. Apply time-release fertilizers that control rate of release.
7. Following pond fertilization do not undertake water exchanges.
8. Do not fertilize ponds if significant risks of over-flows are indicated (e.g. during extreme weather events).
9. Store fertilizers in separate facilities to other chemicals and feeds. Storage facilities should be protected from the elements and provide an impermeable floor to prevent seepage and run-off.

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\(^{(1)}\) The reference by Knud-Hansen, K.D., 1998. Pond Fertilization: Ecological Approach and Practical Application. Pond Dynamics/Aquaculture Collaborative Research Support Program, Corvallis, Oregon, USA, provides information on use of an algal bioassay for estimating pond fertilization requirements. As well, basic soil and water test kits can be employed to estimate the needs for specific nutrient inputs.

\(^{(2)}\) Excess feeds and wastes from cultured fish may result in adequate nutrient input into ponds. As well, although likely to be uncommon in Oman, ponds may receive nutrients in agricultural run-off. Excess fertilization results in hypernutrification causing excessive algal blooming resulting in increased oxygen demand. Effluents from such ponds will also contain higher organic matter levels and increased phosphorus and nitrogen levels of receiving waters.
10. Purchase fertilizers in required amounts only to avoid carryover between production cycles.
11. Clean spilled fertilizer and re-bag fertilizers from ripped containers.

5.6 Use of wastewater and excreta

The use of wastewaters and excreta to fertilize fish and shrimp ponds to increase pond primary productivity is a commonly employed technique in Asia.(1) The use of excreta and wastewaters has mainly been confined to extensive and semi-intensive production systems. However, due to changes in production intensity these practices are on the decline. Nevertheless, unintentional use of contaminated water may still occur, particularly in highly urbanized areas. In Oman, as in other Islamic nations, the use of night-soil and human waste waters as fertilizers for food production is commonly considered haram although examples of the consumption of fish grown in waters receiving human waste are known in Saudi Arabia and overhanging latrines in aquaculture ponds are relatively commonplace in Bangladesh, China, Indonesia, Viet Nam and elsewhere. For aquacultured food animals intended for the Islamic marketplace therefore, it is imperative that design criteria for facilities take this into consideration. Where exports are not destined for the Islamic market, strict adherence to guidelines is a prerequisite to ensure environmental and human safety. In the case of the latter, hazards, including excreta-related pathogens, food-borne trematodes, chemicals and skin irritants may affect workers, consumers and local communities.(2)

5.7 BMPs for wastewater and excreta

When wastewaters are used for aquaculture production environmental and human health issues become of extreme importance. The following, although not strictly environmental in coverage represents basic guidelines for the use of wastewater and excreta:

1. Do not use human wastewaters or excreta during production of any aquacultured organism.
2. Treat wastewaters and excreta appropriately to reduce risks of disease.
   A. Drying of excrement to allow die-off periods before applications
   B. Prevention of cross-contamination
   C. Storage systems should use vector barriers and repellents
3. When employed, workforce must be provided with appropriate protective equipment.
4. Planned use of wastewater and excreta should be accentuated in site development plans.
   A. Design site to avoid all surface water pollution
   B. Greater attention must be paid to flooding and similar factors during the construction phase
   C. Larger and more robust canals must be used as buffer zones.
5. All employees and visitors to the site should have access to safe supplies of drinking water and sanitation facilities that are suitably isolated from production areas.
6. A proactive stand in promoting health and hygiene should be taken.
7. Workforce should be provided with relevant immunizations.
8. Effective disease vector-intermediate host control programmes must be put in place even following primary treatment (see 2 above).
9. Application procedures should minimize the potential for workforce exposure to treated excrement.
10. The facility must be secured to prevent members of the local community using ponds for play and otherwise.

11. Animals grown in wastewater/excrement treated ponds must be depurated for appropriate periods before harvesting.
12. Processing methods must ensure against likelihood of gut contents coming into contact with edible portion of flesh.
13. Signs should be deployed warning the public and new employees of the use of wastewater/excreta during production.
14. Extension education of local communities should be provided to reduce risk of unwitting removal and consumption of contaminated products.
6.0 Preventing escapees

Fish escapes may cause various risks to the environment. These include heightened risks for the introduction of pathogens, inter-breeding and genetic pollution of conspecifics, predation and competition for food and space, including breeding and nesting areas, damage to breeding sites, nursery areas and feeding grounds and negative impacts on other commercial activities (tourism, sport and traditional fisheries). Tilapia has already been introduced into the Sultanate of Oman. This was undertaken by the Ministry of Health as a measure to control mosquitoes. Although the negative impacts of these fish on local surroundings have not been quantified, preliminary observations and the experience of other countries would suggest that the indigenous freshwater fishes of Oman have experienced a negative impact.\(^{(1)}\)

Clearly, escapees also represent financial loss to producers. Three methods of reducing, or limiting the negative impacts of escapees, are prevention, genetic compatibility and genetic isolation. Prevention demands actively reducing the chances of escape by more effectively managing potential causes, such as equipment failure. Genetic compatibility includes the culture of local species derived from defined broodstock. Genetic isolation can be used (e.g., sterilization of cultured fish) to diminish chances of interspecific hybridizations.

Table 5.1 Examples of diseases associated with wastewater and excreta-fed aquaculture production.\(^{(2)}\)

<table>
<thead>
<tr>
<th>Hazard</th>
<th>Route of exposure</th>
<th>Relative risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bacteria</td>
<td>Contact &amp; consumption</td>
<td>Low-medium</td>
</tr>
<tr>
<td>Helminths</td>
<td>Contact &amp; consumption</td>
<td>Low-high</td>
</tr>
<tr>
<td>Trematodes</td>
<td>Contact &amp; consumption</td>
<td>Low-high</td>
</tr>
<tr>
<td>Protozoa</td>
<td>Contact &amp; consumption</td>
<td>Low-medium</td>
</tr>
<tr>
<td>Viruses</td>
<td>Contact &amp; consumption</td>
<td>Low-medium</td>
</tr>
<tr>
<td>Skin irritants</td>
<td>Contact</td>
<td>Medium-high</td>
</tr>
<tr>
<td>Vector-borne pathogens</td>
<td>Vector contact</td>
<td>Nil-medium</td>
</tr>
<tr>
<td>Chemicals</td>
<td>Contact &amp; consumption</td>
<td>Nil-medium</td>
</tr>
</tbody>
</table>

In Oman, which exhibits great biodiversity in aquatic species, and especially in its fish fauna, numerous local species (e.g., Indian white shrimp, various groupers, cobia and breams) offer ample opportunities for substitution with traditionally cultivated animals such as European sea bream and bass. The difficulties encountered with such exchanges with commonly cultured non-native species, are often not as complex as is thought since opportunities exist for crossover of culture technologies. Genetic isolation can be accomplished using techniques such as triploidization or use of monosex fish that are unable to breed with local species or survive in the surrounding environment. A general rule of thumb for any national aquaculture development program should be to employ native species only.

6.1 BMPs for eliminating escapees

1. Select sites that are not prone to flooding or at risk due to severe weather and locate all sites above known flood elevations.
2. Chose sites that are distant from high population densities of predators, including annual migratory

\(^{(1)}\) For examples, see the review by: Leveque, C., 1997. Introductions of exotic fish species in tropical freshwaters: purposes and consequences. Bulletin Français de la Peche et de la Pisciculture, 34491-79 ,5-.
routes – this reduces the possibility of predators dropping cultured animals into surrounding water bodies.

3. Obey all national regulations and guidelines relating to species that can be imported, exported, cultured or sold live nationally or internationally.

4. Ensure that constructed ponds achieve minimum standards for structural integrity (e.g. use of correct compaction and stabilization methods for embankments, use of 3:1 side slopes to minimize erosion due to floodwaters).

5. Undertake structural inspections of embankments and other animal retaining devices on a daily basis.

6. Use fencing to decrease risks of predator site entry and thefts which may result in escapes.

7. Screen all inlets and outlets to prevent escapes and to obstruct entry of predators.

8. Use redundancy when implementing barriers to fish escape and predator entry.

9. Use bird nets over fish handling areas to prevent predation-based escapes.

10. Only undertake fish handling operations (e.g., grading, sorting, harvesting) during clement weather and under constant visual inspection. During handling ensure that additional safety nets are used to secure the active area against possible escapes. Use only equipment that is fitting for the activity.

11. Define and implement a site security plan to ensure against theft, vandalism and ecoterrorism.

12. Incorporate different surveillance methods (video, visual) and use inspections from different points of view (sea, land, air, remote, etc.) to ensure site security.

13. Vary timing of specific security checks to reduce theft of cultured animals and associated escapees.
   A. Install alarm systems
   B. Inform local law enforcement agency of security procedures and consult them for ideas to improve overall site protection
   C. Request that law enforcement agency places site on watch list for mobile patrols when these are used
   D. Keep site security plan confidential

14. When practical, do not culture non-native species.

15. Ascertain that broodstock originate from the same genetic stock as wild animals in the culture area (see Appendix).
   A. When possible check genetic background of brood animals with that of wild conspecifics
   B. Collect broodstock only within a 300 km radius of the facility

16. Purchase eggs and or juveniles from reputable (preferably government certified) local suppliers

17. Employ sterilization methods (e.g., triploidization) to negate inter-breeding of escapees with wild fish.

18. When possible, recapture escapees using legally permissible methods.

19. Continuously scrutinize, adjust and improve management actions intended to eliminate fish escapes.

7.0 Predator control

High stocking densities of animals of various sizes, corralled into an environment generally with shallow waters presents predators with feeding opportunities rarely encountered in the wild. And, all farms experience losses due to predation. The impact of predators on production can be insignificant to the catastrophic, with in certain areas, recorded losses sometimes being as high as 70%.(1) The variety of predators encountered in global aquaculture is immense but in the Sultanate of Oman the major cause of predation of cultured fish and shrimp will likely be birds (Table 7.1; however, see BMPs for cage aquaculture). Birds also present a special problem in terms of disease since they act

(1) Unfortunately studies on losses due to predation in tropical aquaculture are rare, thus the need to use a salmonid example: USDA-NASS, 2006. Trout production. United States Department of Agriculture, Washington D.C., USA.
as vectors for adult stages of digenetic trematodes and may spread bacterial and other infections inadvertently through faeces and regurgitated food or by mistakenly dropping diseased fish and shrimp into uninfected ponds. Predator control actions should be developed to minimize interactions while ensuring that wildlife is protected. The environmental effect of predation is to decrease production efficiency and hence resource use while increasing the chances of disease spreading from cultured to wild populations.

Although complete exclusion of predators is possible with the use of enclosed facilities such as recirculating systems, or through fence protection of small ponds, effective depredation methods generally rely on a suite of management approaches.

### 7.1 BMPs for depredation

1. Follow laws and regulations relating to the protection of all wildlife.
2. Consider predator behaviour and distribution during the site selection process.
3. Avoid areas that attract predator congregations such as pumping stations and nesting sites
   - A. Select sites away from breeding grounds
   - B. Reject sites that are close to migration routes
   - C. Refuse areas already densely populated by prey items and especially those that are the targeted species for cultivation
4. Design facilities to reduce losses to predators.
   - A. Locate holding facilities with smaller animals near to offices and laboratories and areas of high human activity
   - B. Use smaller pond sizes to minimize ease of predator relocation
   - C. Remove ground cover and natural roosting items from the site
   - D. Employ spikes, nets and grease to deter birds from non-removable roosting sites
   - E. Use intake exclusion devices to avoid introduction of predatory fish
   - F. Secure the site with fencing
5. Identify the predator(s) responsible for losses to assist in developing specific management strategies.
6. Remove mortalities immediately since these may attract predators.
   - A. Dispose of mortalities correctly
   - B. Harvest and cull sick or moribund fish as part of an integrated health management plan
7. Vary farm work schedules.
   - A. Prevent predators getting used to human activity patterns
   - B. Ensure activity around entire area of farm
8. Use predator nets\(^{(1)}\) and other exclusion and management devices and deterrents.
   - A. Use hardened coatings for longevity
   - B. Use acoustic (e.g., taped alarm calls, fireworks) and visual (e.g., scarecrows with flapping clothes, dummies of eagles and owls, flashing lights) deterrents
   - C. Avoid use of devices that can harm or entangle predators
   - D. Ensure anti-predator devices are maintained regularly
   - E. Use acoustic wildlife scaring devices only between sunrise and sunset
   - F. Completely dry ponds after draining for harvest to remove predacious fishes.
9. Use dogs when practical (i.e., when suitable housing available) to scare away potential predators.

\(^{(1)}\) All cover nets should be taut and of high-visibility colour. Typical mesh sizes for bird predator nets are 47.5- cm.
8.0 Health management

8.1 The cost of disease

It has been estimated that mortalities due to disease outbreaks cost shrimp aquaculture over OMR 1 billion a year,(1) while worldwide, aquaculture losses attributed to disease exceed OMR 2.5 billion annually. These figures do not take into account losses due to reduced performance of animals with sub-clinical infections and stocks that have recovered from disease outbreaks. Nor do they take into account losses in primary inputs (feeds etc.), and hence direct environmental impacts, attributable to mortalities, or the socioeconomic consequences of farm closures. Most aquaculture facilities experience chronic stock losses throughout production cycles which are often explained away as “natural mortalities” of unknown aetiology. These losses, especially for species with extended production cycles, can account for 510% or more of stocked animals and are often accepted nonchalantly by producers. Tolerance of such fatalities is a dangerous attitude but remains a mindset that seems to extend across the industry and even to researchers. An inherent risk associated with the relaxed approach to chronic deaths however is that these losses may be due to latent infections. Under conditions of stress, such latent infections may develop into serious epizootics which have the potential to result in devastating losses and transfers of diseases to wild populations.

8.2 The risks of disease transfer

Only in comparatively recent times has a scientific link between diseases derived from aquaculture and infections in wild fishes been established beyond reasonable doubt.(2),(3) Nevertheless, many farm-wild animal disease interactions still remain inferred rather than scientifically proven as exemplified by sea louse infestations. Comparatively little information is available on the negative ecological consequences of such events although some assessments suggest that sea louse transfers from cultured to wild fish have serious penalties on wild populations.(4)

It is important to emphasize that disease associations are mutual: there is equal likelihood that pathogens from wild animals will infect farmed stocks, whether finfish, shellfish or mollusks, and vice versa. Thus, epidemiological evidence demonstrates the transmission of furunculosis, caused by Aeromonas salmonicida, from farmed-to-wild and wild-to-cultured salmonids.(5) In the former case, the involvement of escapees has often been suspected.

Moreover, the potential exists for disease transfer between molluscs, crustaceans and finfish. A particularly insidious aspect of aquaculture however, has been the introduction of diseases to new geographic locations due to stocking, and egg and broodstock importations (Fig. 8.1). These occurrences have been well documented and in certain instances have resulted in devastating consequences to natural populations of finfish and shellfish alike. A good example of the spread and negative impacts

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(4) For example see Krkošek, M., Lewis, M.A., Morton, A., Frazier, L.N., Volpe, J.P., 2006. Epizootics of wild fish induced by farmed fish. Proceedings of the National Academy of Sciences 103, 1550615510-. However, also see: Beamish, R.J., Jones, S., Neville, C., et al., 2006. Exceptional marine survival of pink salmon suggests that farmed Atlantic salmon and Pacific salmon can coexist successfully in a marine ecosystem on the Pacific coast. ICES Journal of Marine Science 63, 13261337- which tends to refute claims relating to sea lice infestations.
of imported diseases is seen with the crayfish plague caused by the fungus *Aphanomyces astaci*. This disease was imported into Europe from North America during the last century\(^{(1)}\) and has eradicated crayfish stocks from certain areas of the continent and caused serious declines in populations and fisheries elsewhere.

Clearly, the aquaculture industry must do everything possible to ensure against the transfer of diseases into wild populations. It has been suggested that farm-level management should only be considered as a part of disease risk-reduction schemes which would be more effective if developed on a watershed or even national basis.\(^{(2)}\) Nevertheless reducing disease incidence and preventing escapees from individual farms represent an important goal in moderating environmental impacts of aquaculture.

*Table 7.1* Given the aridity of its environment the variety of birds found in the Sultanate is impressive. Particularly abundant are seabirds and these represent potential predators. Of the 486 species catalogued for the nation\(^{(3)}\) however, comparatively few species, as outlined below, will be a hindrance to shrimp and fish farms. Blue blocks represent months during which the species is known to be present.

<table>
<thead>
<tr>
<th>SPECIES</th>
<th>COMMON NAME</th>
<th>JFMAMJJASOND</th>
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</thead>
<tbody>
<tr>
<td><em>Larus hemprichii</em></td>
<td>Sooty gull</td>
<td></td>
</tr>
<tr>
<td><em>L. genei</em></td>
<td>Slender billed gull</td>
<td></td>
</tr>
<tr>
<td><em>L. heuglini</em></td>
<td>Siberian gull</td>
<td></td>
</tr>
<tr>
<td><em>L. cachinnans</em></td>
<td>Caspian gull</td>
<td></td>
</tr>
<tr>
<td><em>L. ichthyaeus</em></td>
<td>Great black-headed gull</td>
<td></td>
</tr>
<tr>
<td><em>Dromas ardeola</em></td>
<td>Crab plover</td>
<td></td>
</tr>
<tr>
<td><em>Sula dactylatra</em></td>
<td>Masked booby</td>
<td></td>
</tr>
<tr>
<td><em>Phalacrocorax carbo</em></td>
<td>Cormorant</td>
<td></td>
</tr>
<tr>
<td><em>P. nigrogularis</em></td>
<td>Socotra cormorant</td>
<td></td>
</tr>
<tr>
<td><em>Halcyon chloris</em></td>
<td>White-collared kingfish</td>
<td></td>
</tr>
<tr>
<td><em>H. atthis</em></td>
<td>Common kingfisher</td>
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<tr>
<td><em>Pandion haliaetus</em></td>
<td>Osprey</td>
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<tr>
<td><em>Haematopus ostralegus</em></td>
<td>Oystercatcher</td>
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<tr>
<td><em>Egretta garzetta</em></td>
<td>Little egret</td>
<td></td>
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<tr>
<td><em>E. alba</em></td>
<td>Great white egret</td>
<td></td>
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<tr>
<td><em>E. gularis</em></td>
<td>Western reef heron</td>
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<tr>
<td><em>Nycticorax nycticorax</em></td>
<td>Night heron</td>
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<tr>
<td><em>Ardea purpurea</em></td>
<td>Purple heron</td>
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<tr>
<td><em>Ardea cinerea</em></td>
<td>Grey heron</td>
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<tr>
<td><em>Butorides striatus</em></td>
<td>Striated heron</td>
<td></td>
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<tr>
<td><em>Ardeola ralloides</em></td>
<td>Squacco heron</td>
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8.3 BMPs for health management

In order to reduce the risks of transferring diseases to wild populations:

1. Comply with all national aquatic animal health guidelines.
2. Select sites that decrease the possibility of disease outbreaks.
   A. Reduce physiological stress (temperature fluctuations etc.)
   B. Ensure availability of appropriate volumes and high quality water supplies
   C. Avoid areas subject to storm surges that may breach biosecurity measures
3. Comply with all national aquatic animal health guidelines.
4. Select sites that decrease the possibility of disease outbreaks.
   A. Reduce physiological stress (temperature fluctuations etc.)
   B. Ensure availability of appropriate volumes and high quality water supplies
   C. Avoid areas subject to storm surges that may breach biosecurity measures

5. Formulate pathogen-specific integrated pest management plans to lessen risk of disease transfer.
   A. Employ biosecurity measures
   B. Develop surveillance and response programs
   C. Tend to treatments in a rapid manner
   D. Use non-chemical treatments
   E. Ensure good site selection
   F. Vaccinate whenever economically feasible
   G. Control vectors of disease
   H. Use site fallowing procedures
   I. Manage stock to break pathogen life cycles

6. Manage the facility correctly.
   A. Use disease-resistant/selectively bred stocks when available
   B. Avoid over-crowding and decrease stress factors (temperature fluctuations, poor quality feeds, etc.)
C. Inspect stocked animals on a daily basis and check for changes in behaviour, colour, etc.
D. Use high quality feeds and recommended rationing
E. Maintain daily records of mortalities
F. Consult fish veterinarian as soon as problems detected

7. Develop biosecurity plan.
   A. Practice good hygiene throughout the facility
   B. Limit traffic of people around the facility (ergonomics)
   C. Limit transfers of fish around the facility
   D. Fallow sites at appropriate cycles
   E. Separate year classes during production cycle
   F. Use quarantine for all in-coming seed, broodstock and on-growing animals
   G. Develop communication plan between producers
   H. Use 3rd party audits to assess all aspects of farm operation and biosecurity measures
   I. Train employees

8. Decrease risks of introducing disease.
   A. Obtain seed and other stocks from reputable sources
   B. Demand certificate of health
   C. Maintain containment during transport and transfers
   D. Maintain rigorous records of all seed and animal transfers
   E. Inspect fish before their entry onto facility grounds
   F. Use quarantine facilities for new seeds and stocks
   G. Disinfect all equipment and when possible, water
   H. Use system of logging for people traffic
   I. Control predators

9. Decrease risks of disease spreading throughout the facility.
   A. Localize and isolate disease outbreaks immediately
   B. Disinfect everything
   C. Initiate section quarantine
   D. Inform employees of quarantine areas

10. Remove mortalities immediately.
11. Prevent fish escape and wherever possible do not discharge water from infected ponds, tanks or raceways.

8.4 Use of probiotics, immunostimulants and similar products

In the recent past a number of products have entered the marketplace claiming positive health benefits for treated animals. Many of these products are delivered to cultured fish and shrimp as feed additives although some may be added directly to the culture water. Examples of such additives include pre-, syn- and probiotics and immunostimulants. These have been successfully deployed in both laboratory and field environments and interesting results have been reported with regard to increasing resistance of cultured fish to dinoflagellates, bacteria and even viral infections. \(^{(1)}\)

Although no real environmental impact is apparent through the application of these products, it is possible that by enhancing the ability of farmed animals to withstand and survive pathogens, that this may lead to increased water column populations of pathogenic viruses, bacteria and fungi due to increased pathogen shedding. In turn there exists the prospect of increased localized disease occurrence.

in wild animals. The use of such products should be undertaken with diligence. Indeed, until more farm-level trials provide categorical evidence for their efficacy it is perhaps better for producers to apply these additives using a precautionary approach. Certainly, it would be wise for producers to await results of trials from accredited institutions before investing in such product lines since their use, unless attractive in terms of substantially increasing production performance of treated animals will inevitably lead to reductions in operational profitability.

*Figure 8.2 Several commercially available products make claims regarding symbiotic, prebiotic, probiotic and immunostimulating properties. These product lines are most often incorporated into feeds at feed mills by the request of the feed purchaser. However, they can also be bought for top dressing of feeds which can be undertaken on-farm.*

### 8.5 Chemical pollution and aquaculture

A comprehensive review of all chemicals used in commercial aquaculture and their potential for negative impacts on the environment is provided by GESAMP.\(^{(1)}\) The persistence of chemicals in the environment is dependent on physicochemical factors that affect their solubility and reactivity. Important factors include temperature, pH, DO, salinity, water turbidity and light intensity. Biological factors also influence the longevity of chemicals in the environment including microbial action and bioaccumulation and biomagnifications in food chains. Most chemicals used in aquaculture however,

have limited persistence although there are some exceptions to this rule\(^{(1)}\). Particular concern has been raised regarding the development of resistant strains of microbes due to overuse or inappropriate applications of antibiotics.\(^{(2)}\) In-depth consideration of the conscientious application of antibiotics by the aquaculture industry is provided in a recent FAO technical report.\(^{(3)}\) The use of antibiotics has declined since the introduction of vaccines although the cost of the latter sometimes precludes their exploitation. Vaccines also have the negative, albeit short-term effect, of reducing feed conversion efficiencies\(^{(4)}\) and are available for a restricted group of mainly fish bacterial diseases. Other methods that can reduce the on-farm use of chemicals that may enter and taint the environment and its organisms include the use of preventative management practices as well as novel feed ingredients that appear to enhance or stimulate immune function in fish and shellfish.\(^{(5)}\) There is a strong disincentive to employ chemicals in aquaculture because these simply raise the costs of production and thence decrease profit margins.

**8.6 BMPs for minimizing chemical use**

1. Reduce the risks of disease outbreaks using good husbandry practices.
2. Use vaccines to prevent the occurrence of disease.
3. Obtain accurate diagnoses before treating a disease.\(^{(6)}\)
4. Assess antimicrobial resistance before applying antibiotics.
5. Only use approved water-treatment chemicals and drugs.
6. Follow manufacturer’s instructions for all approved chemicals.
7. Maintain accurate records of all on-farm chemical usage.
8. Provide usage training for all employees who may come into contact with chemicals on site.
9. Handle and store all chemicals in accordance with the manufacturer’s instructions.
   - A. All chemicals should be secured to prevent unauthorized use, contamination or possible mistreatments.
   - B. Un-used medicaments and other chemicals should be disposed of using applicable regulations and sites
   - C. Maintain a Materials Safety Data Sheet (MSDS) for all chemicals held on site\(^{(7)}\)

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\(^{(2)}\) See: Agerso, Y., Bruun, M.S., Dalsgaard, I., Larsen, J.L., 2007. The tetracycline resistance gene tet(E) is frequently occurring and present on large horizontally transferable plasmids in Aeromonas spp. From fish farms. Aquaculture, 266, 4752- for example of transfer of antibiotic resistant genes between different strains of bacteria.


\(^{(6)}\) It is essential that the causative agent of losses in aquaculture is identified by professional fish, shrimp or molluscan health experts. Many diseases are not caused by bacterial infection such that the use of antibiotics is often inappropriate, environmentally and economically damaging to the producer and increases the risk of causing resistant strains of pathogens to develop.

\(^{(7)}\) Today, most chemicals shipped by manufacturers include a MSDS. These sheets should be deposited in a freely accessible place and employees made aware of the emergency procedures for dealing with exposures, spillage and environmental contamination.
9.0 Handling mortalities

Mortalities occur at all facilities and range in seriousness from chronic losses of a few per day or week to mass mortalities due to disease or environmental stressors such as rapid oxygen depletion. Dead animals may float or sink but irrespective of the buoyancy exhibited carcasses must be removed. In warm waters, as expected in the Sultanate, dead fish would usually be expected to float before decomposing and sinking. Dead animals will be retained in all systems due to netting and embankments such that the risks of entry into the surrounding environment will be minimized. Rapid removal of mortalities is encouraged for three main production and environment-related reasons: they attract predators, can cause deterioration in water quality and may act as a source of disease.

9.1 BMPs for mortalities

1. Mortalities should be removed from the site as soon as identified.
2. Samples should be taken for later autopsy where unexplained mortalities occur.
3. Moribund fish and shrimp and those individuals under obvious stress should be removed from production facilities to decrease stress on other stocked animals and to reduce the possibilities of such animals acting as disease reservoirs.
4. Only humane methods should be used for the euthanasia of moribund animals.
5. Animal carcasses must be disposed of in accordance with applicable regulations(1) and must not be discharged with overflow water.

10.0 Facility operation and maintenance

The vast majority, of especially intensive aquaculture operations, must maintain, store and handle various chemicals (fertilizers, anaesthetics, feeds, fuels, lubricants, etc.). As well, larger operations employ a range of gear such as tractors, earth movers, aerators, seining equipment and so forth to assist in production. It is imperative from economic and environmental perspectives that such investments are protected and operated in an efficient manner. A cornerstone to production efficiency is the creation and use of meaningful production planning and record-keeping systems.(2) Good record-keeping is a feature of all well-operated and maintained facilities. There should be regular information retained on all aspects of production and these records should be reviewed and used to improve operational and environmental management of the facility. By ensuring regular maintenance of all farm components, as well as operating in accordance with relevant laws and regulations economic and environmental performance will be improved. In addition, by providing employees with appropriate training on a regular basis, economic and environmental benefits will likewise accrue.

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(1) Disposal of mortalities is often undertaken using site-specific methods but may be subject to local regulations to prevent odours. Five methods of mortality disposal may be contemplated including: burial in a landfill, incineration, composting, rendering for animal feeds (e.g., ensilation), ground and used for fertilizer. When carcases are buried they should be interred at a depth of 30 cm and at least 95 m distant from wells and other bodies of freshwater and residences and 30 m away from public roads and footpaths. Burial sites should not be subject to flooding. Where carcases are to be transported off site then they should be retained in leak-proof containers.

(2) Commercially available farm management and record-keeping software is available both freely and for sale. The latter are usually more thorough in their coverage and have been developed also to assist in decision-making processes.
10.1 BMPs for facility operation and maintenance

1. Maintain the facility in good condition.
2. Retain a strict schedule for facility inspection.
   
   A. Daily
   i. Inspect all water supply and control structures for physical and leaks
   ii. Adjust water flow with changes in stocking densities
   iii. Clean all debris from retaining structures and inlets
   iv. Check piping for leaks, blockage and damage
   v. Schedule maintenance and replacement of all suspect system components
   
   A. Monthly
   i. Check all buildings for safety and structural integrity
   ii. Repair cracks and damage to avoid further weakening or deterioration of buildings
   iii. Check all roads, walkways, bridges and similar infrastructure for status, and repair as needed
   iv. Inspect all feed and chemical storage areas, including those for fuel oil, gas, etc., for signs of leakage or structural damage and the presence of vermin. Take corrective action where necessary

3. Check and maintain all equipment in good working order.
   
   A. Use the better equipment available (or affordable) and develop maintenance schedules together with the equipment supplier where appropriate.
   B. Maintain a file on each piece of equipment noting its service and performance history and containing its operating manuals and warranty information
   C. Maintain an inventory of critical components that are subject to regular failure (e.g., pumps, piping)
   D. Check all vehicles and maintain schedule to prevent fuel or oil leaks
   E. Train all personnel in the use of each piece of equipment
   D. Ensure personnel are familiar with the location of backups, tools, spare parts, etc.

4. Maintain fuel and chemical storage areas in accordance with all applicable regulations.

5. Develop an emergency response plan for chemical and fuel leakage and spillage events and ensure that all personnel have been trained in reactions necessary for clean-up and containment.

6. Collect and dispose of solid waste regularly.
   
   A. Install waste containers at convenient locations on the farm
   B. Empty and dispose of waste in permitted landfill or through incineration or by other approved method

7. Items to incorporate in record-keeping and log books should include information on:
   
   A. Water flow
   B. Water quality
   C. Animal inventory
   D. Feeding schedules
   E. Waste treatment
   F. Fish mortalities and predation
   G. Health monitoring
   H. Antibiotic, vaccine and chemical use
   I. Equipment maintenance
   J. Employee training
   K. Employee injury
APPENDICES
Appendix 1. BMPs for Net Pen Aquaculture

Next to ponds, net pen or cage operations are the second most common system employed for farming fish.\(^1\) There are considerable variations in net pen design and materials employed in their construction (Fig. 1). Recent innovations include the development of submersible systems that release aquaculturists from near-shore locations and enable use of deep-sea sites. The most sophisticated net pen designs incorporate remote sensing capabilities to monitor water quality parameters such as temperature, salinity, dissolved oxygen and currents; automatic feeding stations and video surveillance systems. But these structures represent the exception rather than the norm, largely due to high capital costs. Indeed, many of the new generation net pens have been heavily reliant on government grants and subsidies for their development.

**Figure A11- Considerable variation in net pen design exists. Many of the more recent architectures examine the feasibility of manufacturing submersible systems that reduce aesthetic impact whereas other designs have considered containment a priority.**

Net pens are distinct from other aquaculture systems in that water flow is not controlled and energy is not required to move the culture medium. Although net pens are more temporary than any other aquaculture system they do require a system of land-based support. This may include jetties, boat houses, feed sheds, laboratory, office and operational buildings, such as boarding houses for personnel. Also unlike other aquaculture techniques, net pens are considered as open systems, such that all activities and operations inside the facility have a direct effect on the surrounding environment and vice versa. Accordingly, net pen operations present various risks to the environment that may be influenced by site selection, production intensity and the characteristics of the cultured organism.\(^2\)

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It is because of the open nature of net pen operations that they have received more scrutiny and criticism by environmental activists than any other animal production system, other than shrimp ponds. Consequently, it is essential that net pen operators embrace and adhere to a strict set of specific BMPs to quell the fears of its opponents.

The following guidelines should be incorporated into the more generic BMPs outlined in previous sections of this manual.
A1- 1 Site selection

As with all other aquaculture operations care during the site selection phase can have significant benefits in reducing the environmental impact potential of net pen farming. Well-chosen locations will optimize fish health and performance, minimize production costs, and take account of employee safety. Often net pen site selection represents a precarious balancing act. For example, on one hand high energy sites may reduce the negative effects of production on the benthos whereas on the other, they may expose workers and pens to higher degrees of risk. Assistance in initial assessment of the suitability of sites for cage aquaculture can be gained using gratis and commercial software.\(^{(1)}\)

1. Undertake in-depth environmental site inspections.
   A. Assess the meteorological and hydrographical conditions of the site using multiple sampling sites.
   B. Obtain historical and seasonal datasets of site characteristics such as weather conditions, tidal measurements and current velocities and patterns from national surveys and other sources (e.g., Universities, Ministries).
   C. Determine wind fetch for all compass directions over a season to estimate maximum wave height.
   D. Measure site water depths and current circulation patterns and speeds.
   E. Log seabed types and characterize epibenthic and benthic species diversity, composition and abundance.
   F. Characterize annual fluctuations in critical water quality parameters (e.g., temperature, salinity, turbidity, dissolved oxygen).

2. Reject sites that have intense fluctuations in weather or tidal conditions.
   A basic principle in any animal husbandry is that farmers maintain access to their stock throughout the year. This enables effective animal management, disease surveillance and feeding adjustments to be made while also permitting general farm maintenance to proceed unhindered. Clearly, severe changes in weather and tidal conditions may jeopardize access to net pens while also placing workers in unsafe environments. Moreover, violent fluctuations in prevailing weather conditions are known to impact animal welfare and product quality. For example, buffeting of fish against nets can cause de-scaling followed by the onset of disease.\(^{(2)}\)

3. Choose sites with appropriate depth and suitable seabed type and profile.
   A rule of thumb in coastal operations has been to site net pens at water depths that are twice that of the proposed structure itself. This principle assumes that such seabed clearance, when combined with good water exchange, will result in adequate mixing and dispersal of solid wastes while allowing good water flow through the production unit. Siting of net pens should take account of seabed type and profile. This enables appropriate selection of anchorage and mooring types. Deeper locations are generally associated with higher wave amplitude and this must be taken into consideration since anchorage and structural stressors will be greater.

4. Opt for sites that have good mixing characteristics and water exchange.
   Good water velocity ensures adequate mixing and dispersal of solid wastes while increasing the chances of ensuring even water quality within the net pen. Evaluation of the seabed’s sediment type provides an indication of water velocity and whether an area is subject to deposition.
   A. Do not select sea bed that is silty or muddy since this generally indicates poor water velocity and a propensity for sedimentation.

\(^{(1)}\) For example, the CADS_TOOL (Cage Aquaculture Decision Support Tool), produced by the Australian Institute of Marine Science as a part of a Australian Center for International Agricultural Research project, is available free of charge. The tool uses basic input information to help in determining the feasibility of using a specific site based on hydrometeorological, substrate, water quality, and socioeconomic factors and models: http://www.aims.gov.au/docs/research/sustainable-use/tropical-aquaculture/cads-tool.html

B. When possible employ computer modeling to assist in estimating dispersal and mixing of solid wastes and nutrients such as nitrogen and phosphorous.
C. Do not select sites where water velocities exceed the optimal swimming velocity of the species to be cultured since this may result in stress and sub-optimal animal performance.

5. Avoid areas susceptible to harmful algal blooms.
Algal blooms have significant negative impacts especially on caged salmon farming operations. Algae cause mortalities by depleting water column oxygen, by bringing about physical damage to gills and or through toxin accumulation. Losses due death or reduction in production efficiency due to harmful algal blooms therefore, are wasteful of resources and thus have negative impacts on the environment. Risks associated with harmful algal blooms can be reduced by:
A. Siting farms in areas of high water exchange which reduce the occurrence of localized bloom development.
B. Assess nutrient status of local water and sediment and chose areas that are nutrient poor – stay away from up-welling areas.
C. Survey phytoplankton in selected site locale to ensure absence of dinoflagellates and phytoflagellates known to cause bloom problems.
D. Survey sediments for the presence of cysts.
E. Check previous bloom history of areas surrounding the proposed site.

6. Site operations away from environmentally sensitive areas.
A. Examine all biological data with respect to the selected site to evaluate presence of sensitive habitats or plant and animal communities.
B. Check national registry for declared areas of environmental importance (e.g., nature reserves).

7. Select sites away from high concentrations of predators.
A. Inspect for presence, distribution and population densities of potential predators and pests.
B. Steer clear of positions that are close to high concentrations of natural fish populations that may attract predators.
C. Locate site away from other fish farms.

8. Ensure that selected sites do not impede access or area use by others.
A1- 2 Benthic impacts

The affiliation between site management and its oceanographic and geophysical features determine the potential negative environmental impacts that a net pen operation may have. Each farm site is unique in its ability to assimilate, process and convert incoming nutrients – a fact that emphasizes the need for rigorous site assessments before commencing operations. Wastes from net pens include solids such as uneaten feed and faecal material as well as dissolved nutrients such as phosphorus and nitrogen. The negative impacts of solid wastes underneath net pens have been known for some time. These detrimental effects, which include decreases in benthic biodiversity and formation of anoxic sediments, mainly result due to poor site selection. Although some negative effects of cage culture can be relieved by using specialty feeds and feed management, other methods can also be used.

1. Position cages to optimize use of water circulation patterns.
2. Use single-point mooring systems where feasible.
3. Monitor impacts of operations on the benthos.
4. Use a system of rotation and fallowing to allow site recovery.
5. Use polyculture techniques to recover nutrients.

A1- 3 Biofouling

Biofouling, the accumulation of aquatic plants and animals on sub-surface and wet objects, represents a growing problem for net pen aquaculture. Biofouling organisms locate on nets, buoys, boat and service barge hulls, cage collars, ropes, and on anchorage and mooring systems. In certain instances, where their growth is promoted by prevailing conditions, biofouling organisms may become so well established that they inhibit water flow into and out of net pens. This may result in sub-optimal conditions and hence performance of stocked animals. The control of biofouling organisms however, does have environmental consequences since some antifouling methods employ chemicals that may impact non-target species. Moreover, dislodged biofouling organisms may add to sediment accumulation in the site’s area. Consequently, antifouling methods must be addressed in a facility’s environmental planning. Several strategies can be employed to reduce the costs incurred in controlling biofouling.

References:
(2) Net pens and their moorings are physical structures and as such may influence localized direction and speed of currents and water circulation. It is therefore prudent to examine water circulation before and after net pen positioning in order to establish optimal pen placement and arrangement of runways, buoys and moorings to ensure good flushing.
(5) The interval to use between site fallowing to allow benthic remediation is site-specific but should be long enough to ensure complete re-establishment of the benthic communities in place prior to production. An effective quantifiable plan should be constructed to document specific biological, chemical and physical changes that occur. During fallowing net pens can be left in place or removed for use at an alternative location on the site. Fallowing should represent a component of an integrated environmental care and assessment scheme. See Pereira, P.M., Black, K.D., McLusky, D.S., Nickell, T.D., 2003. Recovery of sediments after cessation of marine fish farm production. Aquaculture, 235, 315-330. For consideration of multivariate and univariate analyses with regard to usefulness of different parameters in assessing site recovery.
(6) Over the last decade or so, net pen-based aquaculture facilities have started to employ polyculture techniques in an attempt to recover lost nutrients from feeds and as a way of further reducing environmental impact of net pens. Pen operations incorporate shellfish (Mytilus edulis, Crassostrea gigas) and macrophyte (Porphyra, Gracillaria) lines around production facilities and a number of experimental studies have been commenced to examine the potential for co-culturing other species such as echinoderms (Cook, E.J., Kelly, M.S., 2007. Enhanced production of sea urchin paracentrotus lividus in integrated open-water cultivation with Atlantic salmon Salmo salar. Aquaculture, 273, 573-585). Similar methods, which use settlement ponds from shrimp farms are examining the potential for seaweed culture and the production of sea cucumbers in Oman.
fouling.
1. Select sites with low biofouling risk.\(^{(1)}\)
2. Develop and implement an integrated antifouling management plan.
3. Use site rotation and fallowing to reduce populations of fouling organisms.
4. Where fouling occurs near the surface of nets, use air drying to reduce fouling and if possible collect debris for disposal on land.
5. Change and wash nets regularly to ensure that fouling does not impact production efficiency. Whenever possible, clean nets on land to avoid discharging fouling organisms into the environment.
6. Where essential, only employ approved chemical antifouling agents.\(^{(2)}\)

**A1 -4 Fish escapees**

The escape of cultured fish, irrespective of whether the animal is a native or non-native species, is a hybrid, or is reared for food, enhancement, bait or ornamental purposes, may cause various risks to the environment. These include introduction of pathogens, breeding with and hence causing genetic pollution of conspecifics, predation and competition for resources (food and space, including breeding and nesting areas), damage to local environments (including breeding, nursery and feeding grounds) and negative impacts on commercial and sports fisheries. Obviously, it is not in the interests of the farmer to lose fish and in general, escapes occur due to natural catastrophes such as typhoons and hurricanes breaching containment systems, failure of systems and or their components, due to human error, as a result of predation and the damage to nets caused by predators, or because of vandalism and poaching. In theory, it may be possible to prevent the escape of all fish but the economics of attaining such a goal may be prohibitive or the technologies required not fully developed. Nevertheless, there are a number of strategies that can be emplaced to firmly limit the possibilities of fish escaping.

1. Obey all national regulations and guidelines relating to species that can be imported, exported, cultured or sold live nationally or internationally.
2. Select the site with due regard to natural hazards such as the occurrence of cyclones, high winds, predator incidence.
3. Use resilient materials for net pen construction with specifications appropriate for the environment in which operations are to take place.
4. All nets should be made from UV stabilised compounds.
5. Ensure correct fastening of nets to collars and double net areas vulnerable to wear. Employ net weights to reduce abrasion points.
6. Develop a testing, maintenance, and emergency repair plan for all equipment.
7. Use surface containment nets to prevent escape by jumping and as a means of reducing aerial predator take.
8. Install jump nets around the net pen perimeter at heights appropriate for the species being cultivated.
9. Employ mooring systems that are able to withstand normal maximum site operating conditions.
10. Visually inspect mooring systems at a minimum twice per year and before and following serious weather events.
11. Employ mooring connectors that exceed break strengths recommended by the net pen manufacturer.
12. Deploy mooring connectors only where specified by the pen manufacturer.

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\(^{(1)}\) Before final site selection check for the presence of known fouling organisms and fouling rates, develop life-cycle charts for problematic species and identify those conditions that trigger reproduction and larval metamorphosis and settlement. Use this information when possible in an integrated management plan. If natural and locally available predators are available for fouling organisms, introduce these to the pen site. For example, blue mussels have been controlled using rock crabs.

\(^{(2)}\) A number of studies have examined the utility of natural products as antifoulants and it is possible through ongoing research and discovery that such products may become available commercially.
13. Inspect mooring systems and cage integrity on a regular scheduled basis.
14. Clearly mark all net pen sites with buoys, navigational lighting and radar deflectors to ensure against collision damage.
15. Develop SOPs for service vessel operations.
   A. Ensure that vessels are appropriately sized and abide by regulations relating to human waste disposal
   B. Vessels must be fuelled at licensed fuelling stations
   C. Identify appropriate operating speeds under varying conditions
   D. Locate suitable positions for mooring
   E. Define weather and sea state conditions for normal operations
   F. Require a downwind, down current approach for all vessels to minimize collision accidents
   G. All fuel spills must be cleaned up as quickly as possible and reported as required by law
   H. A post-operation clean-up plan must be developed to minimize discharge into the sea
   I. Ensure that boat personnel are fully trained
16. Define and implement a site security plan to ensure against theft, vandalism and ecoterrorism.
   A. Incorporate different surveillance methods (video, visual) and use surveillance from different points of view (sea, land, air, remote, etc.)
   B. Vary timing of specific security checks
   C. Install alarm systems
   D. Inform local law enforcement agency of security procedures and consult them for ideas to improve overall site protection
   E. Request that law enforcement agency places site on watch list for mobile patrols
   F. Keep site security plan confidential
17. Develop SOPs for all planned intensive fish handling, grading, transportation and transfer operations.
   A. Conduct all fish handling operations only during clement weather conditions
   B. Ensure presence of experienced supervisor during operations
   C. Use appropriate equipment for the job at hand
   D. Ensure that all farm personnel are trained in specific handling operations
   E. Deploy safety nets to prevent fish escaping during handling
18. Continuously scrutinize, adjust and improve management actions intended to eliminate fish escapes.
19. When possible, recapture escapees using legally permissible methods.

A1 -5 Predator control

Aggregations of farm animals have always attracted predators and net pen operations are no exception to this rule. Commercial producers experience losses from a wide variety of predators including seals, sea lions and other pinnipeds, otters, sharks, birds and even reptiles. Sometimes predation is directed at individual fish and this is most common with bird predation. At other times, predators may cause physical damage to net pens in efforts to gain access to food. Shark predation on net pens has apparently been on the rise over the last decade, perhaps providing a further indication of the declines experienced in commercial fisheries. Sharks tend to mount all-out frontal assaults on nets, attempting to rip holes in retaining walls. Success can have the potential effect of releasing thousands of animals into the environment. Failures, on the other hand, may result in shark entanglement and death. Producers must be conscientious in not only protecting their investment but also in achieving harmony with the environment and its fauna. For these reasons, a number of solutions may be put into effect.

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(1) For feed barges and accommodation units that require permanent and semi-permanent moorage, take into account water and wind direction and velocity, tidal flux and wave patterns to reduce possibilities of collision damage. Position moorings wherever possible so that in the event that a barge or vessel breaks free, it moves away from the facility.
into effect to curtail the potential negative effects of predation. Together the offered responses can be placed into a wider-ranging predator deterrence program.

1. Site selection should consider predator behaviour and distribution.
   A. Comply with all laws that protect threatened and endangered species
   B. Avoid areas that attract predator congregations such as pumping stations, river mouths and nesting sites
   C. Choose sites that are distant from shark aggregations such as breeding grounds, drop offs and channels near sand flats
   D. Reject sites that are close to migration routes
   E. Decline areas that already possess large resident populations of prey

2. Remove mortalities immediately since these may attract predators
   A. Dispose of mortalities correctly- keep in a cooler unit for later disposal on land
   B. Harvest and cull sick or moribund fish
   C. Circumvent blood loss into the water column as this may attract sharks
   D. Vary farm work schedules
   E. Prevent predators getting used to human activity patterns
   F. Use different routes and approaches for boats
   G. Ensure activity around entire area of farm

3. Use predator nets(1) and other exclusion devices and deterrents
   A. Use hardened coatings for longevity
   B. Use acoustic (e.g., taped alarm calls, fireworks and underwater high decibel sounds) and visual (e.g., scarecrows with flapping clothes, dummies of eagles and owls, flashing lights) deterrents
   C. Avoid use of devices that can harm or entangle predators
   D. Instigate a maintenance schedule

4. Use dogs when practical

5. Employ spikes, nets and grease to deter birds from roosting sites

Figure A12- Whenever possible roosting and bird perching sites should be treated to deter predators. Increased activity around cages often serves to scare predators away but persistent birds may ignore even this!

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(1) All cover nets should be taut and of high-visibility colour. Typical mesh sizes for bird predator nets are 47.5- cm; those for sharks and pinnipeds are 1020- cm.
A1 -6 Facility operation and maintenance

Because they operate in public waters, net pen-based businesses are generally subject to greater scrutiny than other forms of aquaculture production. Those who fail to operate and maintain their facilities at a minimal acceptable level risk rapid withdrawal of permits and licences and loss of investment. Serious offenders may endanger their further involvement in national aquaculture operations or indeed, farming in other waters due to loss of reputation. It is imperative therefore, that all producers abide by the appropriate BMPs to protect the environment and their livelihood. One of the most challenging issues that face sea-bound aquaculture is the management of solid and liquid wastes and special attention to this concern must be stressed to all employees and specific plans for handling and disposal developed. When feasible all operations (e.g., processing) that can be undertaken onshore should be done so.

1. Production planning activities will always be undertaken using strategies that minimize any possible environmental impact.
2. All operators are required to conduct annual systematic reviews of their farming activities and to adjust and improve management actions wherever possible.
3. All operations should incorporate a written log that must be made available for review to Ministry personnel for comment and assessment during inspections.
4. All solid wastes (e.g., feed bags, waste feed, mortalities, packaging materials, waste netting, worn or replaced equipment and components) must be collected and returned to shore for disposal and recycling whenever possible.
5. All nets and mooring equipment must be maintained intact and, when accidentally lost following storms etc., gear must be actively sought and recovered within 30 days of the event. If considered a navigational hazard, gear must be marked with buoys.
6. No items of equipment or gear shall be stored on the seabed.
7. Soaps, disinfectants and chemicals used during production and daily activities must not be discharged from the facility.(1)

Appendix 2. BMPs for pond cultivation of marine shrimp

Shrimp farming, more than any other form of aquaculture, has caused serious concerns from environmental, social and public groups due to the perceived and real environmental damage and social injustice associated with the industry; especially during the late 1980s when a “gold rush” mentality was in evidence. Several species of marine shrimp are cultivated around the world, the most common being Pacific white-legged shrimp Litopenaeus vannamei and black tiger shrimp Penaeus monodon. In the Sultanate of Oman it is unlikely that either of the species should be cultured since alternative indigenous species, such as L. indicus are equally viable from size, growth and economical viewpoints.

A2 -1 Basic production methods

Irrespective of species, most marine shrimp are cultured in coastal ponds although there has been an increased interest in culturing shrimp in inland ponds where suitable saline waters are available\(^1\) as well as in fresh water.\(^2\) Postlarval shrimp are stocked in saline ponds (140- ‰) at variable densities depending on the species and experience of the farmer, origin of stock and environmental conditions. Ponds are typically treated with fertilizer during the first few weeks of production to encourage natural production of live feeds. From 3+ months onwards, commercial shrimp feeds are then applied to permit higher growth rates. There is some discussion in the literature relating to the importance of feeds as the primary source of nutrition of growing shrimp – it has been suggested that animals may be feeding on bioflocs and bacteria that form on feed pellets.\(^3\) Mechanical aeration is often used to increase primary production of ponds. Using variable methods, production from shrimp ponds can be from 500 kg/ha to over 10000 kg/ha in super intensive farms that also use a degree of water exchange. With good management and luck in terms of lack of disease issues, two crops of shrimp can be produced per year in tropical areas.

Ponds are usually completely drained for harvesting with pond bottoms being allowed to dry between crops. Sediment acidity may be neutralized with the application of limestone or lime and the bottoms may be tilled for aeration purposes. Where sedimentation has been heavy during production, a proportion may be removed prior to the new production cycle.

The following guidelines should be incorporated into the more generic BMPs outlined in previous sections of this manual.

(1) 75 McLean, E., Reid, B., Fegan, D., Kuhn, D. and Craig, S.R., 2006. Total replacement of fishmeal with an organically certified yeast-based protein in Pacific white shrimp (Litopenaeus vannamei) diets: Laboratory and field trials. Ribarstvo, 64, 4758-.


A2- 2 Site selection

Take account of the general guiding principles for site selection and facility construction. As with other aquaculture ventures, poorly sited facilities have negative environmental impacts and often fail economically. The better sites for shrimp farms are on flat or gradually sloping grounds above the inter-tidal zone. Inland pond sites can be used where there is no risk of salinization of land or water sources.

1. Build new shrimp farms above the inter-tidal zone with due attention to 100 year floods and other unusual events (cyclones, tsunamis).
2. Take into account the fact that the Intergovernmental Panel on Climate Change foresees an increase in unusual climate events such that historical records may be a poor indicator of historical inclemencies.\(^1\)
3. Ensure that construction does not lead to loss of productive agricultural lands or other sensitive environments such as mangroves.
4. Make sure that permeable soils are sealed using clay barriers or artificial membranes.
5. Protect earthworks from erosion using correct compaction and sealing techniques.
6. Use 3:1 slopes on all sandy embankments.
7. Orientate and size ponds in accordance with prevailing wind directions to reduce wave-based erosion of embankments and levees.
8. Do not site facility in areas that have reached carrying capacity for aquaculture.
9. Maintain buffer zones between habitat corridors, other farms and users.
10. Site farms away from known high predator densities and animal migratory routes.
11. Do not use ground water for salinity control.
12. Minimize effluent and sediment discharge from ponds into the environment.
13. Use water reuse and pond recirculation methods during production and harvesting.
14. Use collected sediments for farm renovations and growth
15. Build settlement and sedimentation ponds into the farm’s design for water inlet and discharge.

A2- 3 Sourcing broodstock and post-larvae

Shrimp farming has experienced various stages during its evolution. Initial farms pumped coastal water into ponds and raised shrimp contained in the water to a marketable size. Subsequently, the industry paid collectors to gather postlarvae which were then stocked into ponds. As science and technology developed, broodstock were collected from the wild to supply hatcheries. This method has subsequently been developed into captive broodstock-based hatcheries that produce specific pathogen free postlarvae. Nonetheless, all methods of postlarvae production and capture are still employed with larvae and brood collections having negative consequences to regional biodiversity and fisheries production.

1. Comply with all national regulations relating to the importation of shrimp.
2. Use only hatchery-reared postlarvae and broodstock.
3. Purchase SPF broodstock or postlarvae to enhance biosecurity and reduce the incidence of disease.
4. Retain purchased broodstock and postlarvae in quarantine to reduce risks of introducing disease throughout the facility.
5. Use stress test to evaluate postlarval quality before stocking.
6. Destroy and dispose of any diseased stocks using regulated methods.

\(^{1}\) See: www.ipcc.ch
A2 -4 Feeds and feeding

As with other forms of intensive aquaculture, feeds account for 50+% of the variable operating costs of intensive shrimp operations. Feed waste in addition to representing financial loss can affect pond water quality and production potential. Build up of organic matter and a decrease in water column DO predispose shrimp to disease through stress while also being problematic for the discharge of nutrients with the associated problems of hypernutrification and eutrophication of the environment. As noted, concern has also been levelled at the use of fish meal in aquaculture production and the actual feeding behaviour of shrimp (op cit.) may indeed negate the need for expensive fish meals in aquafeeds for shrimp. All BMPs noted under the general section on feeds and feeding should be followed. In addition:

1. Use feeding trays to monitor feeding behaviour and as a method of optimizing feed inputs.
2. Feed 35- times per day to optimize feed efficiency and growth.
3. Maximize the contribution of natural pond production through liming and fertilization.
4. Do not use raw seafood or other animal wastes as feeds.

A2- 5 Effluent control

During shrimp production, ponds are drained during harvesting and discharges occur following rainfall and water exchanges to maintain pond water quality. Effluents from shrimp farms tend to have increased nutrient levels, suspended solids and organic matter content relative to other aquaculture operations. Shrimp farm effluents are also potential sources of pathogens to other farms and wild stocks. Factors that affect the mixing and dilution processes for effluents in coastal areas include coastal tidal fluxes, longshore currents, morphology of seabeds, distance of discharge from shore when piped and so forth. In addition to correct site selection principles, the negative environmental consequences of shrimp farming may be reduced with due regard to:

1. Use of sedimentation ponds and traps when discharging water from ponds.
2. Employment of artificially created mangroves as natural biofilters.
3. Reduction of water discharge by enhancing management of pond water quality and through aeration.
4. Recirculation and reuse of water during harvesting and other water flushing events via sedimentation ponds acting as reservoirs for refilling of other production ponds.
5. Monitoring off-site water quality to ensure nil effect of effluents.
6. Dry, till and lime pond bottoms to increase organic matter decomposition.
7. Treat wet soils to kill disease vectors and enhance organic matter decomposition.
8. Dispose of sediments properly – use as embankment repair materials and to stabilize sandy areas.

A2- 6 Miscellanea

BMPs for predator control, health management and facility operation and maintenance are equally covered in the general guiding principles section and that on net pen farming. An emerging issue of increasing global importance relates to food safety for which farmed shrimp have received increasing attention due to tainting by antibiotics and other chemicals. Clearly, no banned veterinary drugs or other chemicals should be used during culture operations and those that are legitimately employed should be properly applied and correct withdrawal period adhered to. During harvest, special attention should be given to sanitary methods which should extend to post-harvest handling and transportation.
A2- 7 Social responsibility

Unlike other forms of aquaculture, shrimp farming has come under fire due to issues relating to social injustice. There are new demands by consumers for products that are not only produced in a sustainable manner but also with the fair trade and justice tags attached – shrimp farms therefore should take charge of social responsibility to develop and operate facilities in a socially responsible way that benefits the farm, the local community through reducing poverty without compromising the environment.

1. Minimize conflicts with local communities.
2. Ensure that aquaculture developments are mutually beneficial and incorporate fair hiring of local inhabitants.
3. Make sure that the welfare and safety of farm workers is taken care of.
4. Provide appropriate training opportunities for all workers in order to enhance their value and to increase their contribution to environmental and social sustainability of operations.
5. Instigate outreach and extension into the community regarding the value of the farming operation to regional development.
Appendix 3. BMPs for the cultivation of marine bivalves

In the Sultanate of Oman interest has already been levelled at the potential for the cultivation of abalone and the nation’s coastline provides many sites that offer high prospects for mollusc culture. Rather than gastropods such as abalone, it is the bivalve molluscs that account for the majority of shellfish farmed on a global basis – a production that accounts for around 25% of all aquacultured tonnage. Commonly farmed bivalves include oysters, scallops, mussels and clams. All major groups of farmed mollusc have representatives in Omani waters and the aquaculture potential of some of these has already been examined.

Bivalves obtain their nutritional requirements through filter feeding – removing suspended particles from the water column using currents that are created via the animal’s gills. Particles removed by filter feeding vary in size and include phytoplankton, detritus, zooplankton, bacterial and other materials. Of the ingested filtered particles however, only a small percentage is assimilated with the majority being excreted before ingestion as pseudo-faeces, or as faeces following ingestion. It is these two “faecal” masses that are of concern from an environmental impact perspective.

A3 -1 Basic cultivation practices

The environmental impact potential of shellfish culture operations is very much related to the methods of production employed. Depending on species, hatcheries may be used to hold broodstock and to rear larvae in tanks to early juvenile stages after which they are transferred to grow-out sites. Hatcheries are generally located at near-shore sites which are able to supply good quality water. Water exchange in brood, larval and juvenile tanks may be undertaken daily depending on temperature and feeding strategy employed. Water quality control, especially for brood animals, is critical during spawning induction and different species have different requirements for temperature, salinity, depth and so on. Broodstock is generally taken from the wild based on size, morphology and colour. Once established broods can be used over several seasons to supply juvenile demands (see BMPs for broodstock collection from the wild). Where appropriate, eggs may be collected and separated using mesh screens. Incubation periods vary with species as too does metamorphosis and settlement.

Production of feeds represents significant time and space allocation to most commercial shellfish hatcheries and several types of algae are reared to satisfy nutritional requirements of broods and seed.

In the hatchery, spat or seed may be suspended on mesh screens with water being forced up from the bottom of tanks to provide feed and maintain water quality. Alternatively, wooden trays, lined with plastic with a thin layer of bottom sand, can be used. The trays are placed into a raceway-like tank. In the open sea, an up-welling system that employs either pumps or tide to deliver water/feed may be used. These systems are often termed FLUPSYs (floating upwelling systems). Another open-sea method places aggregate-covered seed in shallow subtidal or intertidal areas which have been protected with baffles and or pen systems. Another option for seed acquisition is collection from the wild. This may be by direct collection of juveniles by sieving of rough sands and shingles, or by using various methods of collection from natural spatfalls. Spat collectors can be made of different “cultch” materials including mollusc shells, suspended in the water column using ropes or wires, or simply laid out mesh-bottomed wooden trays. Spat are then removed from cultch by scraping or sieving from microcultch (finely ground shell materials). For mussel cultivation spat and juveniles may be dredged with associated environmental damage or collected from spatfalls using various methods. These include use of wooden stakes, ropes suspended from rafts and even mesh netting. Scallop spat can likewise be collected using mesh sacking that has been packed with various substrates or by use of kelp and other species of seaweed hung from ropes suspended on rafts in spatfall areas.
Once a good size has been attained in nurseries, juvenile molluscs are transferred to pre-prepared grow out sites. These are often smooth bottomed beds which support ground culture, tray or bag methods. Short-legged trays usually have a mesh bottom and are employed when substrates may be too muddy. Bag culture encloses shellfish in nylon mesh bags which are placed directly onto a substrate. Similar to bag culture is the use of lantern nets and even specialized plastic individual grow-out units as seen for scallop culture.

Most nations have set regulations regarding shellfish aquaculture operations because the farming occurs on public properties. Usually a system of leases is used to allot areas of seabed that can be used for farming operations. Legislation is also in place regarding quality assurance of the seafood produced. This is because there are dangers inherent in molluscan farming that are not so apparent when producing fish and shrimp. These generally consider the bioaccumulation of pollutants and the potential for accrual of unsafe bacterial loads.

A3 -2 Site selection

Sites for shellfish farming should be selected using criteria that take account of the growth and survival of the species to be cultured. Decisive factors used in selecting appropriate sites include prevailing temperature and salinity, natural production of the surrounding waters and the carrying capacity of the site. Site selection should also take account of possible detrimental effects of human activity, disease organisms and harmful algal blooms on production potential. The scale of negative benthic impacts on sites is dependent on the intensity of production and tidal flushing. Environmental impacts on benthic diversity therefore, will be site-specific ranging from decreased DO associated with increased nutrient loading and sedimentation through to changes in benthic community composition due to increased predation rates.

A3- 3 BMPs for site selection and facility construction

1. Choose sites that exhibit optimal conditions for the species to be cultured (salinity, substrate, oxygen and water flow).
2. Reject sites that express high suspended sediment loads or with history of harmful algal blooms.
3. Avoid areas that are known to have high incidence of shellfish diseases.
4. Evade areas prone to runoff from industry and other human activities.
5. Examine historical climatological and meteorological datasets to gain an overall view of high and

(1) See: McKindsey, C.W., Thetmeyer, H., landry, T., Silvert, W., 2006. Review of recent carrying capacity models for bivalve culture and recommendations for research and management. Aquaculture, 261, 451462- for discussion of models and tools used in assessing carrying capacity based on physical, production, ecological and social carrying capacity.

low data points for each criterion.(1)  
6. To avoid grounding and assist in dispersal of wastes during production, make sure that water column depth is suitable for the method of cultivation employed.(2)  
7. Avoid areas high in aquatic vegetation to reduce negative impacts on areas such as seagrass beds which act as nurseries for fish and invertebrates.  
8. Check for existing leases, charted natural resources (e.g., corals, sea grass beds) and take these into consideration during site planning.  
9. Designate access routes to and from shellfish beds to avoid negative perambulation impacts.  
10. Make sure that siting of shellfish culture operations do not create navigational or access hazards.  
11. Site land-based facilities (hatcheries, laboratories, grow-out tanks) to minimize impacts (see general BMPs for site selection) and to ensure sufficient volumes of quality water supplies.  
12. Use signs to mark lease boundaries, structures and equipment.  
13. Use buoys to indicate submerged structures such as rafts and anchors.  
14. Remove damaged or heavily fouled markers and dispose of in designated area. Replace if necessary.  
15. Provide enough space between rafts and other containment structures to allow easy access and working space.  
17. Be polite to visitors and use these opportunities for extension and education purposes.  

**A3-4 Facility operation and maintenance**  
Like net pens, shellfish are grown in public waters and all operations must take account of multiple users. Application of the following BMPs should be practiced:  
1. Cultivate only native species.  
2. When non-native species are cultured sterilize animals using triploidization methods.  
3. Inspect all gears and replace and repair when necessary.  
4. Make sure all gears are secured appropriately.  
5. For aesthetic purposes, whenever possible standardize colour use for all equipment (nets, buoys, rafts).  
6. Mark all gear with identification tags.  
7. Check sites immediately following inclement weather events, such as storms, to ensure gears are intact and not causing navigational or other hazards.  
8. Remove all un-used and aged gears quickly.  
9. When boats are used ensure that no mechanical damage occurs to marine life and habitat, keep to speed limits to reduce wave erosion events and noise.  
10. Restrict activities to daylight hours only  
11. Follow good neighbour practices by keeping a lookout for vandalism and lost gears.  
12. Remove refuse from farm area – even when not of farm origin.  
13. Train personnel on the importance of good waste management practices.  

**A3-5 Biofouling**  
Submerged structures are all subject to biofouling and this is a ubiquitous problem for shellfish farmers. Major biofouling organisms include tunicates, mussels, tube worms as well as macroalgae.

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(1) With changes in global climate, regional disturbances in water quality characteristics may occur that fluctuate above and or below norms.  
(2) Selection of sites with inappropriate depth may lead to accumulation of faecal materials and promote degradation in sediment and water quality.
Biofouling organisms can clog the mesh of grow-out nets, bags and cages, restricting water flow and hence depleting DO concentrations and thereby reducing growth performance of stocked animals. The extent to which this colonization occurs depends on site location and type, set depth and to a certain extent seasonality. Biofouling organisms are generally also filter feeders and thus compete with farmed stock for food. Direct biofouling on the shell of cultured molluscs can also reduce shell opening and thereby potentially reduce their respiration and feeding activity. Severe biofouling can greatly increase the weight of culture frames and systems, causing difficulties during harvest and their hauling. Cleansing of systems can be accomplished using high pressure water sprays although when biofouling is excessive or obstinate it may be necessary to switch out gears for cleaning on land after drying. Cleansing of biofouling organisms can result in negative environmental impacts too. For example, removal of macrophytes may result in down-stream environmental and aesthetic problems such as shoreline wash-up, or build up of detritus.

A3- 6 BMPs to manage fouling

Producers should develop an integrated biofouling management program that takes account of early detection, prevention and avoidance of biofouling. Farmers should establish a maximum biofouling index based on levels that are economically, aesthetically and environmentally acceptable.

1. Before site selection is finalized, undertake a seasonal check for biofouling using test structures.
2. Use sites that expose shellfish beds daily for dessication control of biofouling organisms.
3. Inspect gears routinely to ensure adequate water flow is maintained for stocked animals.
4. When necessary clean gear using brushes.
5. Confine cleaning to the aquaculture site – for heavily fouled structures, land, dry and clean, ensuring that landing site is approved for use.
6. Prevent defouled materials from accumulating at downstream sites by removal and disposal at land-fill sites.
7. Clean heavily fouled gears prior to storage.
8. Do not use chemical antifoulants.
A3 -7 Depredation

Because shellfish operations are considered as open aquaculture systems, stocked animals are subject to predation by other marine organisms such as polychaetes, crustaceans, molluscs, echinoderms, finfish, reptiles, birds and mammals. Predation in fact remains one of the major problems encountered by shellfish growers in many parts of the world. It is within the interests of the farmer, therefore, to undertake measures to reduce predation. However, as is the case with other aquaculture operations, many predators of shellfish are protected species such that methods of preventing, excluding or controlling pests must be thoughtful to ensure that these animals and their environment are not harmed.

A3- 8 BMPs for predator control

1. Site selection should consider predator behaviour and distribution.
   A. Comply with all laws that protect threatened and endangered species
   B. Avoid areas that attract predator congregations such as pumping stations and nesting sites
   C. Choose sites that are distant from predator aggregations such as breeding grounds
   D. Reject sites that are close to migration routes
   E. Decline areas that possess large resident populations of prey
   F. Select areas that expose stocked animals to the air for short periods (e.g., during the turning of the tide)

2. Employ predator exclusion devices ensuring that their coatings do not release contaminants into the surrounding environment.

3. Adapt the production cycle to counteract peaks in recruitment of nuisance species. (1)

4. Use containment devices that elevate stocked animals off the seabed (e.g., elevated and covered trays, PVC tubes, etc.) which decreases predation by benthic organisms.

5. Avoid use of anti-predator devices that may entangle and hurt predators.

6. Vary work schedules to prevent predators such as birds becoming used to human activity patterns.

A3 -9 Preventing the introduction of invasive species

Several examples of the importation of shellfish into new geographical regions exist and some of these events have been associated with negative environmental impacts. These include effects relating to the co-importation with, on, or within the introduced species, of a nuisance animal or disease, genetic consequences due to hybridization of the import with native species and negative effects in terms of compromising an ecosystem’s carrying capacity. (2) Clearly, the most effective method of eliminating these detrimental ecological impacts is to ban importation of all species. However, this is sometimes not practical.

A3 -10 BMPs for eliminating introduction of invasives

1. Comply with all national regulations relating to the importation of aquatic organisms.

2. Use only hatchery-reared broodstock and seed whenever possible.

3. Purchase SPF broodstock or seed to enhance biosecurity and reduce the incidence of disease introductions.

4. Retain purchased broodstock and seed in quarantine to reduce risks of introducing invasives and

(1) Because in the Sultanate of Oman predator life-cycles may be extended exclusion devices will likely have to be retained in place throughout production cycles.

5. Remove all non-target species from purchased broodstock (e.g., biofouling organisms).
6. Ensure that discard of non-indigenous animals is undertaken with full biosecurity measures in place (organisms must be non-viable and preferably disposed of at landfill sites).
7. Disinfect all out-going water using UV, ozone, pasteurization (heat), chlorination – making sure to dechlorinate waste water before disposal.
8. Ensure that depuration areas are biosecure – use of screens, netting, etc.
9. Develop in-house broodstock to supply juvenile needs.
10. Maintain records of all imports, transfers, animal movements, etc.
11. Employ sterilization techniques (triploidization).

**A311- Health management**

The shellfish farming industry, like that of the shrimp aquaculture sector, has experienced increasing problems with disease outbreaks, resulting in adverse impacts on environmental quality and collapse of local shellfish stocks. In addition, disease has negatively impacted shellfish fisheries resulting in unemployment and economic decline for local communities. Many serious disease outbreaks have resulted due to importation of brood and seed animals, underlining the rationality of establishing hatcheries based on local broodstocks. As with other forms of aquaculture however, a number of strategies can help reduce the chance of infections and their negative impacts on production and environment. The management options for reducing disease risks have been covered in section 8.3 of the main manual.
Appendix 4. Salinization

Freshwater draw-down can cause salinization of coastal water tables through the encouragement of saltwater volume replacement or intrusion. This has already occurred in certain areas of coastal Oman and is especially evident in the Al-Batinah region (Fig. A21-). Increased water and soil salinity has negative consequences on agricultural production (crop failures, decreased yields). Likewise, saline intrusion also reduces natural supplies of freshwater for household purposes and has negative environmental effects on floral diversity and hence faunal dispersal and variety (e.g. insect and bird).

As well, freshwater resources can become salinized by the entry of local discharge from saline ponds into coastal freshwater areas. Although this last environmentally negative possibility would be rarely encountered in the Sultanate, it should nonetheless be guarded against. Equally, improperly compacted soils or incorrect maintenance of liners can result in seepage of brackish water into freshwater supplies.

A41- BMPs to avoid salinization events

1. Select sites that are away from freshwater supplies.
2. Construct farms to prevent salinization of soils – use membranes and clay liners, construct ditches around farm area to capture sideways water permeation from ponds.
3. Avoid contaminating freshwaters with saline effluents.
4. Route farm effluent pipes away from any freshwater sources.
5. Direct brackish effluents to artificial mangrove biofilters.
6. Do not employ freshwater to dilute seawater supplies.
7. Prevent pond water seepage through clay or plastic membranes into freshwater aquifers.
8. Adopt a policy of measuring salinity in any natural freshwater supply close to the facility.
9. Grow salt-sensitive plants around ponds and ditches as biosensors of salinization events.
10. Reuse and recycle saline waters from production ponds using reservoirs.
11. Discharge pond waters slowly into receiving waters to prevent overflows onto neighbouring agricultural lands.
12. Reuse sediments to replace eroded pond levees and banks.
13. Do not permit excess drawdown of freshwater aquifers.
14. Do not discharge effluents into irrigation canals or onto agricultural lands.

Figure A41-. Maps showing the extent of groundwater salinization (mg L-1) and position of dams (blue squares, left map) along the Al-Batinah coast Oman. Approximately half of the agricultural land in the Sultanate is concentrated along this narrow coastal plain. With increased population pressure and industrial development, greater demands have been placed on groundwater resources causing further elevations in salinity.

Appendix 5. Broodstock collection

Ideally all eggs and seed for aquaculture should come from specialist suppliers derived from broodstock that have been developed in-house. Selectively bred animals tend to be more feed efficient and resistant to disease and stress, grow more evenly and exhibit quality traits that are preferred by customers. However, the establishment and management of quality selective broodstock programs is technically difficult and extremely expensive. In fact there are few such programs globally and less than 5% of organisms used in commercial aquaculture are selectively bred. Many individual farms nevertheless do maintain their own broodstock for the supply of seed while others specialize in seed and fingerling supply only. Even so, commercial aquaculture still employs wild-caught larvae and broodstock and shrimp culture is perhaps one of the better examples of this poor practice. It has been suggested that larval and broodstock collection from the wild has resulted in the collapse of some shrimp fisheries in Asia although poor fisheries management practices cannot be exonerated from the cause either. Clearly however, there is a necessity to collect broodstock at the early stages of new species development for aquaculture and it is important therefore, that BMPs be put in place to minimize the environmental impacts (e.g., loss of biodiversity) that may accrue from such practices. As well, it is now evident that broodstock programs need continuous replacement of founder populations to avoid inbreeding depression and other negative genetic effects.

A5- 1 BMPs for sourcing broodstock, larvae and fingerlings

1. Use only farm-reared animals for broodstock and larval and fingerling supply.
2. Comply with all laws regulating the seed and animal importation.
3. When available purchase only specific pathogen-free (SPF) animals.
4. Use stress tests to evaluate the quality of larvae and fingerlings.(1)
5. Immediately destroy any diseased organisms.

A5- 2 BMPs for collection of broodstock from the wild

When there is an absolute requirement to collect broodstock from the wild the methods employed should comply with BMPs relating to animal escapees.

1. Identify key geographical areas for broodstock collection and divide into different regions or collection zones.
2. Collect broodstock only within a 300 km radius of the facility.
3. When possible use only sanitized equipment for collections.
4. Only employ methods of capture that do not harm animals.
   A. Scoop nets
   B. By diving and hand netting
   C. Trapping
5. Select and retain only animals that are of high quality.
6. Use physical features (e.g., length, condition, head length, shell colour and conformity, etc.) as a guide to selection.
7. Do not collect animals with external damage or deformities.
8. Do not keep broodstock with external signs of disease such as pustules or fin rot.
9. While at sea, maintain collected teleost broodstock in flow-through containers or in aerated keep

(1) Stress tests can evaluate the ability of larval shrimp or fish to tolerate changes in salinity (065‰ -) or the presence of formalin (150200- g/L). Tests should be done in triplicate and survival of 20-100- animals per test monitored every 5 minutes for 1 hour. Salinity tests may be life stage dependent such that higher concentrations of salt (65 % and above) may be needed with older animals as seem for example, with cobia.
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10. On land transfer larger animals into appropriately sized covered labelled tanks supplied with clean filtered water at the collection temperature and salinity. Ensure availability of oxygen and degassing apparatus. For smaller animals (e.g. shrimp, molluscs), individuals can be packed into oxygen-loaded water in polyethylene bags maintained in coolers.

11. Transport collected brood animals to broodstock facility as rapidly as possible.

12. Ensure that holding tanks for brood animals retain identical water quality parameters to transport tanks.

13. Keep newly collected animals in quarantine facilities.

14. When possible house animals in separate containers to avoid disease transfer.

15. All equipment used during broodstock collection should be disinfected and housed in the quarantine area.

16. Use covered tanks and employ depth control and jump nets to prevent occurrence of escapees.

17. Allow for a reasonable recovery and acclimation period before any further animal manipulations are attempted.

18. Avoid exposing broodstock to any known stressors (light and temperature and salinity shocks).

19. Tag individuals (PIT and other internal tags are preferred since they are retained more effectively than external tags) for later identification and breeding purposes.

20. Maintain all information relating to origin of individuals and crosses used.

21. Dispose of any mortalities or moribund animals resulting from collections using appropriate methods.

Figure A51-. Ideally, producers should commence operations with certified specific pathogen-free (SPF) broodstock, fry or larvae. These are available in the international marketplace for shrimp and certain species of marine and freshwater organisms of interest to Omani aquaculture. For example, SPF tilapia eggs, fry, fingerlings and broodstock are available from suppliers in Thailand, Norway, the United States and elsewhere.
Appendix 6. Occupational and community health and safety

Aquaculture operations exhibit a number of safety hazards related to day-to-day operations which should be taken into account as part of social responsibility in terms of running production units. Care should be taken to incorporate a safety plan for workers and site visitors. For the general workforce, Health and Safety Executive manuals should be referenced. The weather of the Sultanate can pose many hazards to the workforce and exposure to the heat and sun, especially during the summer months can represent serious challenges for any work crew. Working in heat can cause dehydration, sunburn, fainting, heat exhaustion, heat stroke and sun poisoning. Clearly, workers must have unhindered access to ample supplies of potable water, take short rest breaks in shaded or cool areas and should wear suitable protection such as sun glasses, sunscreen and hats. Another unique hazard in desert conditions, caused by the processes of wind erosion, is sand storms. Regions impacted, and the magnitude of such events varies but high levels of sand encroachment and storms may occur during dry and windy months or during monsoon events. It is imperative that the workforce be provided with goggles and other protection during such times. Other hazards commonly encountered by workers at aquaculture facilities can be conveniently grouped into three sub-sections:

A6 -1 Physical hazards

Heavy lifting is encountered during normal routine and may include refilling of automated feeders, unloading of trucks, grading and harvesting fish and others. Management measures that can be undertaken to reduce personnel injuries as a result of lifting include:

1. Installation of mechanical and or automated devices to assist in lifting of load greater than 25 kg.
2. Design of working areas that may be adapted to individual workers and tasks.
3. Construction of ponds so that seining activities can be undertaken using trucks.
4. Ensure workforce receives training in correct stance for lifting.

The risks of electrical shock are a real danger during daily operating procedures and a number of deaths in the industry have occurred due to lack of attention to this hazard. Measures that can be taken to avoid the risks of electric shock include:

5. To avoid electric shock, waterproof all electrical installations.
6. Make sure that fuses are used to interrupt power supplies in emergencies and that equipment is grounded.
7. Check to make sure that all cables are undamaged before use.
8. Provide training in correct handling of electrical equipment to reduce risks of short circuiting.
9. Mark any electrical cables buried beneath ground level or underwater.
10. Do not permit use of boats around sub-surface power lines.
11. Wherever possible keep power lines above the water surface.
12. Do not permit employees to work alone when using electrical equipment.

As with electric shocks, drowning has also been responsible for numerous deaths in the aquaculture sector and a number of steps can be taken to prevent these types of tragedy occurring:

13. Insist that all employees wear life-jackets, harnesses and safety clips whenever employees are placed into a situation (e.g., in transit boats and barges, on net pens, during pond harvesting) when drowning hazards exist.
14. Ensure that all personnel are experienced swimmers.
15. Train workforce in sea safety including supervision and CPR.
16. Consider community use of lands near ponds when designing facility.
17. Limit physical interaction of community members with the facility using fencing.
18. Provide wide walkways and fall protection near hazardous locations.

All equipment and machinery is potentially hazardous and may even cause death of users and bystanders. Safe use of such equipment therefore, should be incorporated into training programs for staff.

19. Use machinery and equipment only for its intended purpose.
20. Make sure that equipment is inspected before using.
21. Only competent personnel should use equipment.
22. Do not get on or off vehicles, equipment etc. when in use.
23. Ensure that all moving parts of equipment are provided with guard rails or are enclosed.
24. Make sure that workers on and around equipment do not wear inappropriate clothing or jewellery which may snag in moving parts.
25. Make sure that there is enough space, ventilation and lighting around the equipment.
26. Check operation of alarm systems (visual and audible) daily.
27. Do not remove any component of a machine that has been attached for safety purposes by the manufacturer.
28. Prohibit riding on vehicles and vessels other than in defined seats with safety belts etc. attached.
29. Regularly maintain equipment in accordance with the manufacturer’s instructions.
30. Only use certified service agents during equipment maintenance and repair.

Figure A61-. Boat and net pen crews and visitors should all be provided with life belts and when vessels are in operational mode all crew should be positioned in appropriate areas for boat balance and safety. Cages should provide reasonable walkways with fall nets attached.
A6- 2 Chemical hazards

A number of chemicals are routinely used at aquaculture facilities including those for the treatment of diseases, chemicals that are used to aid production (fertilizers, lime, salt, diluted chlorine, formalin) and others used to induce ovulation and spermiation. Fuels and lubricants can also be included in this section. All chemicals, fuels and lubricants pose a hazard to the environment and to workers who come into contact with them. Most chemicals employed in aquaculture operations are involved in routine operation of vehicles, boats and equipment. The correct handling, transport, storage and disposal of chemicals should be a component of workforce training.

Use only legal and approved chemicals during operations.
Store all chemicals in well lit and ventilated areas according to the manufacturer’s instructions.
Make certain that reactive chemicals are stored separately from each other.
Chemicals should be kept in their original container with labels attached. Safety sheets (MSDS) should be kept in the facility used for storage.
Clean up materials should be available to handle accidental spills (absorbents such as sand and litter etc.).
The amount of chemicals, fuels and lubricant stored on site should not exceed reasonable operational requirements.
Chemicals must be used only in accordance with the manufacturer’s recommendations.
All workers must be provided with appropriate safety equipment when exposed to operational chemicals.
Used or partially used containers of chemicals should be returned to point of sale or disposed of using information on the MSDS.
All hazardous materials should be firmly secured during transportation and should preferably be held in a locked container.
All chemicals should be stored outside of the crew/driver cabin.
Maintain a detailed record of all chemicals transported by specific vehicles.
A6.3 Water-borne diseases

Risks associated with the use of excreta in aquaculture have been mentioned previously (see page 30). Although it is well-established that the eating of undercooked and raw fish is associated with a wide range of human ailments, a growing number of reports highlight concern relating to the potential risks associated with the transfer of aquaculture pathogens to fish farm workers. Good examples of such cases are seen during processing and handling of farmed fish in particular and a number of reports demonstrate transfer of vibriosis and mycobacteriosis. Also, human health risks associated with the use of veterinary medicines has also been considered. A great many of these problems can be avoided with appropriate training and vigilance, the use of protective equipment and good oversight by experienced individuals.

Appendix 7. Checklist for BMPs

All aquaculture operations should be subjected to quarterly or more frequent unannounced inspections. These exercises serve several purposes not least of which is to help the farmer to maintain sustainable development of the operation. Visits also provide a means to check on the commitment of the owner-operator to the national goal of environmental protection and the production of safe, wholesome seafoods. The following checklists provide mostly yes-no answers to operational questions which will aid inspectors in verifying that the obligations of the producer are being met and point to corrective actions necessary to bring production methods back in line with expected national guiding principles.

COMPANY NAME:

SITE NAME & LOCATION:

OPERATIONAL LICENCE NUMBER:

<table>
<thead>
<tr>
<th>GPS Coordinates</th>
<th>Lat:</th>
<th>Long:</th>
<th>Lat:</th>
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<tr>
<td>Inspection date</td>
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<tr>
<td>Inspector's name</td>
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<td>Species cultured</td>
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<tr>
<td>Production (p.a.)</td>
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<tr>
<td>System used</td>
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</tbody>
</table>

Is the operational licence and other certificates current and in order YES . NO .

SYSTEM MANAGEMENT:
Does the farm undertake regular water quality measurement? YES . NO .
If yes, what parameters? (Oxygen, temperature, salinity, etc.) ________________________________
________________________________________________________________________________
How regularly (twice daily, daily, weekly, monthly) is each water quality parameter taken? ______
________________________________________________________________________
Are written records of water quality kept on site? YES . NO .

INVENTORY KEEPING:
Are inventory records kept for each species for each containment system? YES . NO .
If yes, are the inventory records maintained on site? YES . NO .
What type of data is included on the records? (tick) Date fish stocked . Date harvested . Mortalities . Origin of stock . Number of Escapees . Loss due to predation . Others: ____________________________________________________
________________________________________________________________________________

ESCAPEES:
Has the farm experienced any escapees since the last inspection YES . NO .
If yes, how many animals escaped, on what date, what was the cause of systems failure, and what improvements have been made to the facility to reduce the chance of future escapes? ____________
________________________________________________________________________________
________________________________________________________________________________
________________________________________________________________________________

PREDATORS:
Are any predators visible on or near the site? YES . NO .
Are there any signs of predator mortalities (carcases, excessive feathers, etc.)? YES . NO .
Does the farm employ any method(s) for depredation? YES . NO .
If yes to the above, list methods____________________________________________________

MORTALITIES:
How are mortalities stored on site?____________________________________________________
How often are mortalities removed?___________________________________________________
Are mortalities disposed of on site? YES . NO .
If yes to the above, describe method of disposal:_________________________________________
**DRUG & CHEMICAL USAGE:**
Are stocked animals presently being treated? YES . NO .
If yes, are treated containment facilities marked? YES . NO .
Name of therapeutant(s) used:_______________________________________________________
Dosage employed:_________________________________________________________________
Method of delivery (tick): in feed . injection . immersion . other ________________________
Name of prescribing veterinarian:_____________________________________________________
Date of treatment(s):_______________________________________________________________
Withdrawal period to be used for each therapeutant:_____________________________________
Have records of all drug use been kept? YES . NO .
List of other chemicals and their purpose and dates of use:___________________________________
Chemicals are stored in designated secure structures YES . NO .
Chemical storage facility is climate controlled YES . NO .
Storage facility contains powered venting to enable 3 air changes per hour YES . NO .
Structure has impervious flooring (e.g. concrete, metal) YES . NO .
Chemical storage facility has emergency spill kit YES . NO .
Stored chemicals are appropriately separated by containers YES . NO .

**BIOSECURITY:**
Has the farm developed a biosecurity plan? YES . NO .
If yes to the above, have farm workers been trained in biosecurity measures? YES . NO .
Are detailed records of all animal movements maintained? YES . NO .
Are year classes maintained in separate enclosures? YES . NO .
Does the farm have an isolated quarantine facility? YES . NO .
Does farm purchase seed, larvae or fry from suppliers? YES . NO .
If yes, list suppliers and life stage purchased__________________________________________
Are disinfectants readily available on site at appropriate stations? YES . NO .
Does the farm employ pro, pre or synbiotics? YES . NO .
If yes, list products used_____________________________________________________________

**FUEL STORAGE:**
Fuel tanks are above ground to reduce risks of subsurface contamination YES . NO .
Tanks are placed on impermeable surface (e.g. concrete) YES . NO .
A containment dyke surrounds the storage area YES . NO .
A roof is used to protect from the sun and extend longevity YES . NO .
Corner posts are used to protect fuel tanks YES . NO .

**WATER & EFFlUENTS:**
Are ponds and pond drainage systems in a good state of repair? YES . NO .
Is a settlement pond employed before discharge? YES . NO .
If settlement ponds are used are they managed in any way? (e.g., polyculture; provided adequate time
for settlement to occur; pretreated in any way before discharge)
________________________________________________________________________________
________________________________________________________________________________
________________________________________________________________________________
Have artificial wetlands (e.g., mangroves) been planted as biological filters? YES . NO .
Take water quality samples and analyse:_____________________________________________
FEEDS & FEEDING:
Are non-formulated feeds used on site (e.g., trash fish)? YES . NO .
If yes to the above what quantities are used per week and why? _______________________________________________________________________
Does the farm employ automatic feeding systems? YES . NO .
If yes is equipment in good state of repair? YES . NO .
Are species-specific feeds employed? YES . NO .
Are feed tables (owner or manufacturer) used for feeding? YES . NO .
Are life cycle-based feeds employed? YES . NO .
Does the farm record feed use YES . NO .
Does the farm adjust feeding seasonally to take account of appetite loss? YES . NO .
Are feeds stored in clean, dry, vermin-free areas? YES . NO .
Are copies of feed in-and-out records maintained? YES . NO .
Are feeds fed according to manufacturer’s instructions? YES . NO .
Are feeds used on a rotational basis (i.e., last in last out)? YES . NO .
Check feeds for expiry dates and to determine presence of mouldy feeds.
Are medicated feeds stored away from other feeds in a secure area? YES . NO .

POND FERTILIZATION:
Are accurate records kept of type(s) and method(s) of application of fertilizer? YES . NO .
Are methods of fertilizer distribution even? YES . NO .
If no to the above recommend use of liquid fertilizers for more even distribution
Are fertilizers stored in clean, dry, vermin-free facilities? YES . NO .
Are existing bags of fertilizers in good condition (e.g., no rips, spillage)? YES . NO .
Are storage area floors impervious? YES . NO .
Are excess amounts of fertilizer maintained on site? YES . NO .

EMPLOYEES:
Have employees been provided training since last visit YES . NO .
If yes, list training activities _______________________________________________________________________
Have any employees been injured since last visit? YES . NO .
If yes, list injuries and treatments provided _______________________________________________________________________

CAGE-BASED SYSTEMS:
Are cages placed with suitable clearance from seabed at low tide? YES . NO .
What is the nature of the seabed below cages? _______________________________________________________________________
Have there been any algal blooms since last visit? YES . NO .
Were any losses reported due to algal blooms? YES . NO .
If yes to the above, how many animals were lost? _______________________________________________________________________
Cross-check the above with mortality record sheets
Do cages and operations impede access/use to/of the sea to others? YES . NO .
Is a system of rotation employed? YES . NO .
Has the cage anchoring system be examined on a regular basis? YES . NO .
If yes, is there evidence (photographic/log book) of examination? YES . NO .
Has the operator undertaken regular (weekly) dive-based inspections of cages? YES . NO .