Marine Finfish Farmers Association of South Africa
Khala Rd, East London IDZ Zone 1A, Greenfields, 5241 PO Box 5041, Greenfields, 5208 Tel: 083 771 9507 Fax : 086 656 9657

Marine Fish Farming

Environmental Impact Information

Compiled by: Marine Finfish Farmer's Association of South Africa (MFFASA)
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Introduction

The supply of fish from capture fisheries has been flat for more than a decade at around 80 million tons (FAO 2008). With most of the major wild fish stocks now close to being fully exploited, this situation is unlikely to change. However, demand for seafood continues to rise due to population growth, changes in lifestyles (owing to the health benefits of eating fish) and pressures on other food resources. To satisfy this demand for seafood a new agricultural industry has risen - it is “Aquaculture”. Aquaculture is one of the oldest forms of agriculture, originating in the east centuries ago with the extensive cultivation of freshwater fish such as carp. During the past sixty years, aquaculture has evolved into the fastest growing agricultural sector which is no longer an artisanal craft of rural people. It has become a vital economic sector operated by professional managers, scientists and engineers (Nash *et al*., 2000) contributing 46% of world seafood supply now standing at approximately 140 million tons (FAO 2008).

Background

The rapid expansion from extensive pond aquaculture systems to the advanced intensive culture methods used today has led to a growing concern regarding the sustainability of the industry. Modern aquaculture has arrived at a time when environmental knowledge and concern has rarely been higher, and when it must compete with tourism, environmentalists and the general public. Many have labelled aquaculture as a path to environmental disaster due to the mistakes made during the pioneering efforts some 30 years ago - when the industry was starting out. Incidents of severe pollution and irreparable damage have occurred, especially in the coastal waters of pioneer aquaculture countries such as Norway and Scotland. By learning from the mistakes of others, the approach of aquaculture proponents has changed to that of risk mitigation and environmental sustainability. This does not mean that no environmental impact occurs from aquaculture (any activity by man will impact on a pristine environment), but merely means that the impacts are controlled and limited to ensure the continued existence of a healthy environment. This is no different to the evolution that has taken place, albeit faster, in the much more practiced agricultural industry which has had a much longer history.

Any of man’s activities (terrestrial and marine) have an impact on the environment. In the case of terrestrial agriculture, indigenous vegetation needs to be cleared to make way for crops. Even in a conservation area, unnatural barriers such as fences are required. In the marine environment, even the culture of seaweeds causes the deposition of organic matter on the seafloor (Buschmann *et al*., 1996). The key issue is to limit these impacts by implementing sound management practices. This will ensure the continued existence of a healthy environment wherever aquaculture ventures take place.

Different individuals and groups have direct and indirect interests in the use of natural resources and the management of potential environmental impacts. This may be because the individuals are part of a geographical community located close to aquaculture activities, and/or because they are impacted by aquaculture activities, such as fishing organizations, research institutions and conservation organizations. Community perspectives of aquaculture, and the level of understanding of potential environmental impacts, can affect aquaculture development (Productivity

Commission, 2004). By taking an 'open' approach to community concerns, an environment of complete distrust and pessimism towards the marine aquaculture can be avoided (Suryanata & Umemoto, 2005).

The intention of the Marine Finfish Farmers Association of South Africa (MFFASA) is to take an open approach to communicating environmental impact issues on marine fish farming with all stakeholders so that realistic and representative information is transferred. The formulation of this document is an initiative by MFFASA to do just this.

MFFASA and the Marine Aquaculture Code of Conduct

MFFASA Members unanimously accepted the Marine Aquaculture Code of Conduct instituted by the Department of Agriculture, Forestry and Fisheries (DAFF) in 2010. The general principles of this code of conduct are as follows:

1. Marine aquaculture practices should aim to minimize impact on the long-term integrity and genetic diversity of natural marine ecosystems. It is the responsibility of the marine aquaculturist to minimize ecological change resulting from farming practices.

2. Marine aquaculture should be developed and managed in an ecologically sustainable manner with provision for the equitable use of shared resources. The scale of development should not exceed the availability of environmental resources or the capacity of the affected ecosystem to assimilate the changes resulting from farming practices. Marine aquaculturists should take appropriate steps not to jeopardize multiple use of a common resource.

3. Marine aquaculture operations should be monitored for ecological impacts by assessing performance with regard to predetermined environmental quality objectives. This system of monitoring should form a component of a broader regulatory control process and coastal management framework that includes social and economic factors as well as environmental parameters. Marine aquaculturists should support practical and cost effective strategies to ensure that environmental performance standards are met.

4. Selection of appropriate sites for marine aquaculture should take socio-economic factors and specific site characteristics into account. The evaluation of site characteristics should address relevant physical, biological and chemical variables in relation to the requirements of the cultured organism and methods of operation. Marine aquaculturists should also recognize existing Marine Protected Areas and ecologically important areas which have conservation status. Marine aquaculturists must recognize the importance of good site selection, system design and infrastructure to minimize ecological damage.

5. The use of chemical inputs in marine aquaculture which are hazardous to human health or the environment and which can affect the sustainability of the marine aquaculture sector, should be avoided. Marine aquaculturists should strive to minimize the use of agricultural, industrial, or veterinary chemicals and such use should be done in accordance with the relevant legislation (such as the Fertilizers, Farm Feeds, Agricultural Remedies and Stock Remedies Act, 1947 (Act No. 36 of 1947), Medicines and Related Substances Act, 1965 (Act No. 101 of 1965)).

6. The disposal of wastes on land or at sea such as offal, sludge, dead or diseased cultured aquatic animals and excess hazardous chemicals must not constitute a hazard to human health or the environment and should be done in accordance with the relevant legislation (such as the National Environmental Management Act, 1998 (Act No. 107 of 1998), Marine Living Resources Act, 1998 (Act No. 18 of 1998), National Environmental Management: Waste Act, 2008 (Act No. 59 of 2008), National Environmental Management: Integrated Coastal Management Act, 2008 (Act No. 24 of 2008)).

7. The establishment of marine aquaculture operations which could affect ecosystems that span political boundaries should be done in a responsible manner with due respect to neighbouring states and in accordance with international law.

8. The marine aquaculture sector should take cognizance of existing international codes of practice for marine aquaculture-related activities.

9. The translocation of species and the introduction of exotics and genetically modified stocks should be carefully and rigidly controlled and should be done in accordance with the relevant legislation (such as National Environmental Management: Biodiversity Act, 2004 (Act No. 10 of 2004) and the Genetically Modified

Organisms Act, 1997 (Act No. 15 of 1997)). Marine aquaculturists must work in association with the regulatory authorities to minimize adverse genetic, disease and other effects of introductions and transfers on wild stocks.

10. Aquatic animals held in culture should be treated humanely. Marine aquaculturists should take appropriate steps to ensure their stock is maintained in good health and, where relevant, humane and environmentally acceptable methods of slaughter should be used.

11. Products intended for human consumption should be of an acceptable quality and should conform to health standards for seafood as prescribed by the relevant authorities such as SABS. Assurance of product quality requires the use of appropriate technology and compliance with standards and accepted procedures for the cultivation, harvesting, handling, processing, storage and distribution of farmed aquatic animals and their products.

12. The marine aquaculture sector should, where reasonable, co-operate with those involved in research, technological development programs, and training activities that are aimed at expanding knowledge and understanding of marine aquaculture operations and their environmental interactions.

13. The marine aquaculture sector should contribute where possible to implement improvements in technology and in management, where such improvements are reasonably and economically possible and can assist the sustainability of the activity and improve the social and environmental compatibility of marine aquaculture.

14. The marine aquaculture sector should comply with all applicable legislation and regulatory measures to ensure that a productive and well established marine aquaculture industry is maintained in the long term.

15. The marine aquaculture operators should, where possible, consult and cooperate with each other for the development and agreement of standards and objectives.

Marine Aquaculture and the Environment

Marine Finfish farming can be divided into two broad categories – land-based and sea-based culture technologies. The majority of finfish farming to date has made use of sea-based culture systems, utilizing a well established sea cage farming technology. The implementation and development of land-based culture technologies (using intensive re-circulation and pond culture systems for farming marine finfish) for species that are difficult to culture in the sea or where environmental conditions are not ideal for farming has made some significant progress over recent years.

Sea-based culture technologies use natural strategic advantages (e.g. clean, calm, temperature-stable water conditions) to optimise production. Land-based culture systems (especially intensive recirculation systems) adapt on-growing conditions to suit the species being produced. The level of environmental control differs, and so also the environmental impacts. This document will try and address most of the impacts related to these culture methods.

<u>Environmental Assessment and Management Planning</u>

The National Environmental Management Act 1998 (as amended) stipulates that any aquaculture production system that produces more than 20 tons per year on land and 50 tons per year in the sea is deemed a listed activity requiring environmental authorization. Depending on the scope of the activity, it will require either a Basic Assessment or a full Environmental Impact Assessment (EIA). Either way, the law requires an assessment of all environmental impacts before any fish farming activity is allowed.

EIA assessments are required by law before an aquaculture facility can be constructed. During this process potentially negative environmental and social consequences of the facility will be addressed. The biggest concerns are usually related to the discharge of effluent water and the handling of solid wastes. Possible ground water contamination (for land-based facilities) will also receive attention. A detailed construction management plan also needs to be submitted to deal with the impacts of construction on the environment.

Once an Environmental Approval (EA) is obtained, one has to apply for a ‘Right to Engage in Mariculture’. This is normally given for a fixed period of time (usually 15 years) and is subject to specific conditions. Once the right is obtained a annual permit is issued which prescribes certain operating conditions. In the case of sea-based farming an additional process is required in order to obtain a sea lease area if no designated mariculture area has been declared.

Environmental Monitoring

Environmental monitoring serves as a tool for proper environmental management and is normally instituted by DAFF as a requirement to ensure environmental impact compliance. All MFFASA members subscribe to this practice to ensure that minimal environmental impact occurs and to minimise any traces of impact outside of the operating area.

Water quality is routinely monitored in re-circulating aquaculture systems culture water with the following parameters being measured:

- Inorganic nitrogen
- Suspended solids
- Dissolved oxygen
- Temperature
- pH

For the incoming water hydrocarbons and heavy metals are measured periodically. In the effluent water, the above parameters as well as settleable solids are measured.

Various methods of environmental monitoring exist for sea-based farming activities, these include:

- Benthic video transects
- Sediment core sampling
- Water quality analysis

These monitoring practises reveal important information on:

- The visual impact on the seafloor
- The distribution of invertebrates and changes in community structures over time
- The composition of the benthic infauna
- Nutrient enrichment of the water column

Environmental Impacts

In re-circulating aquaculture systems water is continuously treated. Solids are continuously removed from the culture water and oxygen levels are also maintained at a high concentration. Through the use of bio-filtration, ammonia is oxidized to nitrate and the chemical oxygen demand of the water is also reduced (Timmons *et al* 2005). To prevent nitrate accumulation, daily water exchange is used with 10% replacement of the culture volume being standard. Solids that are removed from the main flow can be disposed of relatively easily since they are concentrated in a small volume of water by the filtration process (Costa-Pierce *et al* 2005). The water that is discharged into the environment after solids removal will have a minimal impact on the environment since it has already been biologically treated (Summerfelt *et al* 1999).

Table 1: Typical water quality parameters for an intensive re-circulating aquaculture system (Costa-Pierce *et al* 2005)

Factor	Concentration
TAN	0.5 mg/l
NO^2	0.85 mg/l
NO^3	10.5 mg/l
PO_4	9.71 mg/l

In cage aquaculture the deposition of organic matter below cage fish farms and resultant changes in sediment condition are the most obvious and best studied impacts (Samuelsen *et al*., 1988). The environmental factors that influence how much of this material reaches the sediment directly under sea cages include tidal flow, supply of faecal matter, depth of site, composition, size and behavior of particulate matter ejected, temperature, wind and wave action (Provost, 1996). The deposition of particulate matter from aquaculture net-pens has been identified as the main cause of negative environmental impacts on the water column and benthic environment (Gowen *et al*., 1991; Pillay 1992; Read & Fernandes, 2003; Dosdat, 2001). High deposit rates may cause an accumulation of organic detritus in the sediment if removal by physical, chemical and biological means cannot assimilate such an input. Usually the accumulation of organic output is confined to the area directly beneath the net-pens and its immediate surroundings (Henderson *et al*., 1997; McGhie *et al*.; 2000). Such high waste inputs can produce strong changes in the structure of benthic communities (Karakassis *et al*., 2000; Mirto *et al*., 2002). Feacal matter and feed decaying on the bottom may alter the benthic ecology since bacteria that facilitate the decaying process lower the oxygen levels in the epibenthic layer, and mixing makes the sediment surface layer anoxic (without oxygen). Toxic byproducts of decay (methane and hydrogen sulfide) are also released in the water column (Aure & Stigebrandt, 1990). Organic nitrogen contained within the feed may cause plankton blooms (Dortch *et al*., 1998).

Read & Fernandes (2003) categorized discharges from aquaculture to the aquatic environment as follows: continuous discharges from aquaculture production, periodic discharges from farm activities and periodic discharges of chemicals. Production discharges comprise mainly dissolved and particulate organic and inorganic nutrients. The various dissolved and particulate organic compounds, in the form of faeces, uneaten food and accidental food spillage, include proteins, carbohydrates, lipids, vitamins and pigments. Some inorganic excretory products are also released; mainly ammonium and species-dependent trace quantities of bicarbonate, phosphate and urea. Discharges from farm activities comprise fish processing waste and regulated dumping of mortalities, usually in silage form. Inorganic discharges within this category include detergents and effluent from net washing (anti-foulants and heavy metals). Most of the latter discharges are released from farm activities other than on-growing. The release of chemicals from production sites comprises mainly medicines and anti-foulants.

The benthic effects of fish-farming have been investigated worldwide, although the results of studies from different parts of the globe are not necessarily directly comparable. Many studies have suggested that environmental impact is highly correlated with location (Karakassis *et al*., 1999; Kraufvelin *et al*., 2001). The behavior of any type of organic matter released into the water column depends on the hydrographic conditions, bottom topography and geography of the area in question. The environmental impact of these dissolved products depends on the rate at which nutrients are diluted before being assimilated by the pelagic ecosystem (Read & Fernandes, 2003). In restricted exchange environments, there is a risk of high levels of nutrients accumulating in one area. In shallow waters, with weak currents, particulate matter from aquaculture installations will settle to the bottom close to the discharge point. In this case, continued production can give rise to a rapid local accumulation of waste material on the sea floor (Fernandes *et al*., 2002). Effluent released into deeper waters, or where the bottom is well swept by strong currents, will, in general, be dispersed over a large area (Read *et al*., 2003). Dissolved wastes are also easily dispersed by local currents and although significant increases in concentrations of phosphate and ammonium have been detected near aquaculture facilities, eutrophying effects on plancktonic communities have not been observed in offshore conditions with high water exchange (Beveridge, 1996; Pitta *et al*., 1999; Karakassis, 2001). Offshore aquaculture generally reduces environmental impacts when compared to nearshore aquaculture due to the greater dilution of pollutants in the vast marine environment and the greater forces of dispersal on these pollutants (Gowen *et al*., 1989; Penchang & Newell, 1997; Cellikol, 1999; Emmerson, 1999; Ryan, 2004).

Some studies have shown that 70 to 80% of nutrients added in aquaculture are lost to the environment in the form of metabolic waste, faeces and uneaten food fragments (Kaushik 1998; Lemarié *et al*., 1998; Lupatsch & Kissil, 1998). The quantity and quality of the feed are the most important factors determining nutrient loss to the environment, since these factors determine both feed wastage and excretion loss (Persson, 1990; Cho & Bureau, 1997, Belmonte, 2002). It is not only the chemical composition of the feed that influences the rate at which it is lost to the environment; the feed management is as important as any other factor (Levings, 1994). Vita *et al*. (2004) evaluated the particulate organic waste output originated by Northern bluefin tuna farming through direct measurements in the field with sediment traps. The settling rate of particulates was approximately 14 times the background level. Tuna fattening produced 5.8 mg N kg/fish per day and 9.2 mg P kg/fish per day in particulates. The deposition rates of particulate organic matter obtained in the Vida *et al*. (2004) study are well below the values mentioned in the literature for the culture of other species (Ackefors & Enell, 1994; Lemarie *et al*., 1998; Lupatsch & Kissil, 1998).

In terms of the capacity of restricted exchange environments to assimilate plant nutrients from cage fish culture, it has been argued that sufficient nutrients have been added in some areas to accelerate algal growth and to produce an undesirable disturbance to the balance of organisms and the quality of the water concerned (through the occurrence of harmful blooms, increased oxygen consumption in deep water, and/or increased production of toxins by certain algae) (Midlen & Redding, 1998; Oceanographic Applications to Eutrophication in Regions of Restricted Exchange (OAERRE), 2001). Others have argued that aquaculture contributes only a fraction of the total nutrients added to coastal waters and that the system is well below its assimilative capacity (Black, 2001).

One of the principal conclusions in a recent piece of research by Tett & Edwards (2002) is that, in Scotland, whilst some coastal waters and sea lochs are enriched with anthropogenic nutrients from a range of sources, including aquaculture, physical limiting factors, e.g. light, and biological limiting factors, e.g. grazing, prevent the occurrence of undesirable disturbance in almost all well-documented cases.

Wild fishes tend to concentrate around fish farms (Dempster *et al*., 2002; Rountree, 1989; Pickering & Whitmarsh, 1996). A sediment trap experiment conducted by Vita *et al*. (2004a) showed that about 80% of the organic matter in particle form that actually sinks below the rearing net-pens can be consumed within the first 4 m and never reaches the bottom sediment. The amount of particulate organic matter that actually reaches the bottom beneath the net-pens has been estimated at 20% of the total. Johansson *et al*. (1998) incorporated inert indicator particles into the feed of a fish farm, which were later found in the gut contents of nearby wild fishes. Vita *et al*. (2004a) found that the nutrient quality of the organic matter expelled by fish farms may be significantly changed by wild-fish consumption. Similar trends were found in the sediment, attributable to wild fishes exhausting the high nutrient content of settled particles. Changes in the nutrient quality of fish-farm sediments could be due to direct consumption of particulates by benthic organisms (wild fishes and invertebrates). Biotic assimilation of nutrients helps in the exportation and dispersion of organic wastes resulting from aquaculture activity.

Angel *et al*. (2001) found that in order to limit the discharge of nutrients to the surrounding waters, it is possible to capture and harvest farm effluents by means of the algae and invertebrates that develop around fish cages. This may be accomplished by deploying substrates near fish cages and allowing the naturally occurring “biofouling” community to serve as a biofilter for effluents.

There are currently no guidelines in South Africa in terms of minimum water depth requirements for marine aquaculture. Beveridge (2004) suggests that it is best to hold fish at least 4 – 5 m above the sediments. The South Australian southern bluefin tuna farmers observe a Best Practice Standard of at least 5m above the bottom (Bryars, 2003).

Not only does excessive waste accumulation affect the natural environment, but also the environment of the cultured fish. Unacceptable levels of waste deposition occur when the sediments become anaerobic or anoxic (Chou *et al.*, 2004). Excessive waste accumulation can deplete the dissolved oxygen levels in the benthos, thus changing the aerobic process of waste breakdown to that of anaerobic fermentation. The result of this is the release of methane and hydrogen-sulphide gasses that can be detrimental to fish and animal health. The decrease in oxygen penetration would be more evident in summer with an increase in stocking density, an increase in the amount of feed administered and an increase in water temperature (Danovaro *et al*., 2003). Aguado-Giménez and García-García (2004) found that the nitrogen and phosphorous levels drop during months of lower production (winter). Excessive waste accumulation has a medium to long term effect in the immediate area. However preventing the anaerobic state in the benthos, due to waste accumulation, will change the period of impact to medium (less than one year).

Most studies have shown that the local extent of altered benthic community structure and biomass is limited to less than 50 m from the actual cage site (Hargrave, 2003). Danovaro *et al.* (2003) found that the ratio of microbial to meiofaunal biomass beneath cages is 3 to 4 times higher than control sites. However these ratios returned to normal as soon as the cages were removed. The changes in the benthic community are not only related to waste accumulation, but also related to wave action and other historical factors (Edgar *et al*., 2005).

Good management practises prevent anaerobic conditions. Benthic video transects and sediment core sampling indicates the status of the substrate and aids in management decisions, as conditions of excessive waste accumulation not only affects the environment, but also adversely affect the fish in the cage system. Environmentally friendly stocking densities and feeding practises with minimal feed loss are applied in preventing anaerobic conditions, whilst fallowing (i.e. not stocking some cages or moving of cages to a new area) can be used as a contingency measure. Dissolved nutrients that leach from uneaten feeds, faeces and sediment build-up can be a source of environmental concern. These include inorganic elements and compounds such as nitrogen and phosphates, as well as organic compounds such as ammonia. Studies show that no significant differences exist between the plankton response in the vicinity of fish farms and control sites (Pitta *et al*., 1999). In addition, several studies failed to establish a relationship between farm waste and phytoplankton growth in open sea, even when large inorganic nutrient inputs were observed (Beveridge, 1996).

In an assessment of water quality data by O'Donohoe *et al*. (2000), no significant differences could be found in the levels of dissolved nutrient in Kilkieran Bay (production 3,600 tons), pre- and post-salmon farming. This is not always the case as the significant variation in water quality observed by Tovar *et al*. (2000) was ascribed to low levels of water movement within the river system where aquaculture was practised.

In a study done by Merceron *et al*. (2002), it was found that DO (dissolved oxygen), suspended solids, phosphate, nitrite and nitrate were not affected by the 576 ton salmon farm used in the study. It was however noted that ammonia concentration in close proximity to the farm site was higher than the control sites, but decreased in a short distance from the farm to background levels.

Accumulated waste and excessive feeding strategies will lead to eutrophication. An adaptive management approach will prevent water quality deterioration by adapting feeding strategies according to environmental assessments done by the independent party. The use of fallowing will prevent excessive build-up of nutrients in the substrate layer that can leach into the water column.

Chemical Pollution

Chemical pollution occurs with the inappropriate use of inorganic chemicals in aquaculture practices. Possible effects of chemical use include direct toxicity to non-target organisms, uptake of contaminants by wild fish and shellfish, inhibition of microbiological activity in the sediments below fish cages (thereby affecting the rate of degradation of accumulating organic matter), induction of antibiotic resistance in aquatic organisms including fish pathogens, and concomitant effects on humans (Heffernan, 1999).

In land-based systems the incidence of disease can be decreased effectively through simple biosecurity measures by preventing disease introduction (Lee *et al* 2003). Also treatments that are used in the culture systems are limited to substances that do not negatively affect the bio-filter. Thus antibiotics and other harmful chemicals would not be found in the effluent of re-circulating aquaculture systems (Moller *et al* 2010).

Laboratory studies showed that some of the treatments used in sea-based salmon culture could pose a possible hazard to certain species inhabiting the culture area. However, too little is known about the actual harmful effects of these chemical treatments and thus cannot be condemned before a complete risk and impact assessment of that specific chemical (treatment) has been done (Haya *et al*., 2001).

A wide range of chemicals are used in cage aquaculture and these may be categorized as disinfectants, anti-foulants and veterinary medicines. These are used to control external and internal parasites, or microbial infections (Costello *et al*., 2001). The environmental concerns over the use of chemicals in the aquatic environment relate to: the direct toxicity of the compounds to non-target organisms; the development of resistance to compounds by pathogenic organisms; the prophylactic use of therapeutants and the length of time they remain active in the environment (Costello *et al*., 2001). Antibiotics in medicated fish feed have the potential to induce drug resistance in natural microbial populations. Concentrations of a commonly used antibiotic, oxytetracycline (OTC), largely disappeared within a few weeks, but traces of the antibiotic were detectable for up to 18 months (Samuelsen *et al*., 1992).

DAFF Marine Aquaculture Code of Conduct requires that no chemicals and treatments procedures will be used unless cleared by the governing authorities. Adherence to international codes of conduct regarding chemical usage receives first priority.

Genetic Impacts

The probability of fish escaping from traditional aquaculture systems is so large that the FAO (1995) stated that a new species introduced to aquaculture will be seen as a new species introduced to the wild, no matter how secure the system is. Although findings from research indicate that chances of survival of escaped fish are minimal, there is evidence that a select few will persevere for longer periods (Fowler *et al*., 2003). However, any ecologically competent exotic fish not currently found in wild populations, poses substantial risks. Such risks include potential reductions in the genetic diversity (and resulting ability to adapt to environmental change}, productivity, and fitness of wild fish, leading to possible extinctions (Naylor *et al*., 2005).

There is convincing evidence from literature that farmed fish can have a significant influence on the genetic profile of associated wild populations. The impact would not cause an irreplaceable loss of the resource, as it would merely cause a change in the existing genetic frequencies within the genome of the species. Laura *et al*. (2005) reports on the effects of aquaculture on wild fish populations. They recommend that given the paucity of data regarding actual population consequences of escaped farmed fish on wild populations, and the documented differences between the two types of fish, it seems prudent to treat farmed fish as exotic species with potentially negative consequences for wild populations, particularly when the latter are of conservation concern.

However, the marine environment is considered a homogenous environment with few physical barriers to limit the flow of genes in marine species. Consequently, marine species (migratory species in particular) typically show little variation between populations. A migratory adult life history strategy typically results in a high larval dispersal leading to a low level of genetic differentiation within the species (Klopper, 2005). For example, indications are that dusky kob (*Argyrosomus japonicus*) may display a weak genetic structure that would reduce potential genetic impacts.

Genetic impact would be more or less profound depending on:

1. The nature of the genetic structure of the wild populations - the more defined the structure the more significant the expected impact.

2. The number and frequency of farmed fish escaping into the wild – the higher the number and frequency the more significant the expected impact.
3. Extent of genetic differentiation between the farmed and wild populations – the greater the difference the more significant the expected impact.

The potential genetic impacts of farmed fish on natural fish stocks refers to the possible distortion of natural gene frequencies - hence the genetic structure amongst the surrounding and effected wild populations - being impacted by farmed fish escaping from the farming systems. The potential impact is regulated by the principles of migration as described by Falconer and Mackay (1996). According to their model, the ability of a farmed fish population to affect the genetic diversity of wild populations will be determined by:

1. *The extent of genetic differentiation between the populations*

   The principle at stake is that the less the differentiation between the farmed and wild populations the lower the genetic risk associated with the project. Gene flow in dusky kob in southern Africa appears to be extensive and significant population structuring is not detected (Klopper, 2005). This situation will cause the impact of farmed fish on wild stocks to be less profound, in comparison to species such as salmon and sea bass that demonstrated distinct genetic population structuring. The genetic compatibility between the farmed and wild populations can be retained if sufficient numbers of brood stock are sourced from the surrounding wild populations in a random manner and a mating program is put in place to prevent inbreeding and maintain a sufficient effective population size. The genetic compatibility of farmed and wild populations can also be validated, from time to time, through the use of molecular marker based technologies
2. *The quantities of farmed fish in relation to wild fish*

   The principle at stake is that the lower the number of farmed or escaped fish in relation to the size of the surrounding wild population the lower the genetic risk associated with the project. The maintenance of robust populations of wild fish is recommended as a key to minimizing the effects of escaped fish on wild populations.
3. *The rate of competition, survival and reproduction of farmed fish in comparison to the wild fish*

   A further determinant is the rate of survival and ability of farmed fish to compete with and reproduce amongst the wild populations. It is widely accepted that the ability of farmed fish to survive and reproduce in the wild is significantly lower than that of their wild counterparts. Although no information on this is available in relation to kob, Orpwood *et al*. (2004) reported on competition between hatchery reared and wild salmon and confirmed that wild fish were not affected by the presence of farmed reared fish, even when outnumbered in a ratio of four to one.

Therefore, if measures are put in place to ensure that genetic compatibility of farmed and wild populations are maintained and that the numbers of escaped fish are kept to a minimum, there would be a low risk of the farmed fish to have a significant genetic impact on natural fish stocks.

Recommendations to minimizing genetic differences between escaped and local wild populations are:

1. Use of brood stock from local sources that reflects the genetic profile of wild populations.
2. Maintain genetic variation amongst brood stock populations through the inclusion of adequate numbers and application of appropriate mating designs.
3. Reproductive sterility is recommended as a future key to eliminating the genetic impact of escaped fish.
4. Ensuring awareness of staff in relation to the potential impact of escaped fish on the wild populations.

5. Monitoring programmes should focus on the regular assessment of the comparative genetic profiles of commercial brood stock, farmed stock and wild populations.

Brood stock fish used in fingerling production in South Africa are not genetically modified and are collected from the wild. Taking into account that the genetic composition of the cultured fish does not differ markedly from that of the wild population and that the number of fish escaping will be insignificant compared to the existing wild population, an alteration in the gene frequency of the existing population will be negligible and thus the impact of escaping fish will be minimal in reducing genetic diversity.

Due to the design of land-based culture systems the escape of cultured animals from land-based systems is highly improbable (Timmons *et al* 2005). Recently, genetically modified salmon have been approved for human consumption by the FDA but these will only be permitted to be cultured in land-based re-circulation systems. This indicates that even authorities in developed countries are confident in the ability of these systems to prevent accidental introductions.

Health Management

Monitoring fish health in re-circulating systems is simple since fish are regularly weighed and graded. In re-circulating systems environmental conditions are maintained at an optimum for the cultured species and this together with biosecurity measures helps to prevent diseases (Lee *et al* 2003).

Rapid development of fish culture in marine cages has been associated with an emergence of fish diseases, parasitic diseases in particular. There are many known diseases and parasites associated with finfish (Blaylock & Whelan 2004), and the spread of parasites, viruses and bacterial infections between caged and wild fish populations (from wild to farmed, or vice versa) is a significant concern for the fish farming industry worldwide (Pearson & Black 2001). Disease begins in the wild but amplification and re-transmission under high densities (which is not common naturally) is the key issue.

There are several studies however, that do not paint as ominous a picture. The spread of pathogens from aquaculture fish to wild fish near cages is possible but widespread transmission and disease development in wild stocks is not likely (Hawke, 2008). Disease encountered in offshore aquaculture will be dependent on host species. According to Waknitz, *et al*. (2002) in their review of potential disease impacts from farmed salmon wild stocks:

- The expectation that Atlantic salmon will increase current disease incidence in wild and hatchery salmon is low.
- There is little risk that existing stocks of Atlantic salmon will be a vector for the introduction of an exotic pathogen into wild stocks.
- There is little risk that the development of antibiotic-resistant bacteria in net-pen salmon farms or Atlantic salmon freshwater hatcheries will impact native salmonids, as similar antibiotic resistance often observed in Pacific salmon hatcheries has not been shown to have a negative impact on wild salmon.

There is a general trend to an increase in infections with ectoparasites with direct life cycles and a reduced diversity of parasites in aquaculture, attributed to increased density of fish, repeated introduction of naive hosts, homogenous host populations, fast growth and a potential decrease in genetic diversity. While wild marine fish are hosts to a wide range of parasites, sometimes the dominant parasite in culture is either rare or absent in the same species in the wild. In cases where the dominant parasite species in aquaculture is present in wild fish populations, adverse effects are more obvious in farmed fish. For example, disease and mortality due to monogenean infections can be common in aquaculture but are rare in wild populations (Thoney & Hargis, 1991). Farming fish in marine cages can thus increase the risk of outbreaks of parasitic diseases, including those caused by opportunistic parasites. However, aquaculture has the potential to control parasitic diseases through selective breeding, vaccination and general fish health management (Nowak, 2007). Some parasites can be transmitted from cultured fish to wild populations (Morton *et al*., 2005 and Krkošek *et al*., 2006) and from wild fish to cultured populations (Ho and Nagasawa, 2001 and Rae, 2002).

Cage aquaculture can contribute to the emergence of diseases, particularly those caused by opportunistic ectoparasites with direct life cycles, and the spread to wild populations. A collective approach to fish health management includes the use of healthy fry, quarantine measures, optimized feeding, good husbandry techniques, disease monitoring (surveillance and reporting), sanitation, vaccination, selective breeding, and the responsible use of chemicals and antibiotics when diseases occur (Forrest *et al*., 2007). Overall, the emphasis must be on prevention rather than cure (treatment) as this is the best way to sustain a responsible yet profitable aquaculture venture and an industry at large. General improvements in farm management, in particular cage positioning and setting above the seabed together with improved lease location, significantly reduced the impact of disease organisms on farmed fish (Munday *et al*., 2003; Nowak *et al*., 2004 and Nowak, 2007).

Bio-fouling

Bio-fouling is a term used by fish farmers to refer to marine animals and plants that grow on or inside fish farming equipment, requiring regular cleaning to maintain the equipment. These are the same types of animals that grow on the hull of ships and boats. They attach to a fixed surface (e.g. a net, rope or pipe interior) and remove food particles or nutrients from the water flowing past to sustain themselves and grow.

The most problematic bio-fouling animals are tunicates (sea squirts), bryozoans (moss animals), mussels and barnacles. These animals fix themselves permanently to the fish farming equipment and require preventative or regular removal to keep the farm operating effectively.

Fish farming operations can minimise the impact of bio-fouling organisms by using smooth, plastic coated, knotless mesh on their nets, copper-alloy mesh or anti-foulants. Plastic coated mesh significantly reduces the potential of the larval stages of the fouling organism settling on the fish cage mesh – as the larvae are not able to get a firm grip when they settle and get washed off. The same principle is used in land-based systems where glass-fibre reinforced piping (GRP) is used for seawater extraction and circulation systems.

Copper-alloy mesh, copper based anti-foulants, non-copper based anti-foulants as well as ‘organically accepted’ anti-foulants are available for use in cage-based farming operations. Ships and boats most commonly use copper-based anti-foulants to prevent bio-fouling. The most appropriate measure for a fish farming operation can be determined according to the extent of bio-fouling that is experienced at that particular site (bio-fouling between sites can vary enormously) and also cater for any site specific environmental requirements.

Storm damage

Sea-based fish farming systems are often exposed to the extremes of natural cycles – including large storms at sea. Countries that have well developed sea-based fish farming industries often have a natural wealth of protected, deepwater embayments that are ideal for protecting fish cages from storms, currents and rough seas. While still developing their businesses, these farmers have encouraged their equipment service providers (mooring system and sea-cage manufacturers) to develop technologies to extend their farming operations into more exposed fish farming sites. Today, a sea-cage and mooring system can be designed and installed to weather any stormy seas, only the construction, installation and maintenance costs will need to be increased proportionally.

South Africa has a very exposed coastline with very few bays deep and protected enough to accommodate easy fish farming activities. Cages and mooring systems need to be designed, installed and maintained properly in order to minimise the potential impacts storm damage on these farming systems.

Land-based farming systems are also exposed storms but, generally, the infrastructure used to accommodate these operations comes from an established and experienced construction industry. Seawater intake systems can be vulnerable during storm events and need to be designed, installed and maintained in order to weather any storm. Significant experience with seawater extraction systems for land-based farming systems has been gained from the South African abalone farming industry and is being put into practice for land-based fish farmers.

Feed utilisation

Farmed marine fish are often portrayed negatively in the press because wild fish are used to feed farmed fish. Fish farming operations are accused of killing more than they produce e.g. 'Atlantic salmon takes five pounds of little fish to produce one pound of farmed salmon' (Charles Clover, The End of the Line - Documentary).

In the wild, predatory fish species consume a large amount of natural feed over the course of their lives. It is estimated that a wild carnivorous fish will only convert a tenth of the ingested fish into body weight (Tidwell *et al* 2001). A study of the aquaculture industry in 2007 estimated that it took 2.2 kg of fish to produce a kilogram of farmed fish (Tacon *et al* 2008). When comparing this to the results from capture fisheries where 10 kg of food fish is needed to produce 1 kg carnivorous fish, indications are that aquaculture is a more efficient converter of food fish into a saleable fish product – up to 5 times less demanding on the oceans and fish stocks than wild fish.

Fish feeds are constituted with protein levels anywhere between 30% and 70%, with rest of the feed being made up of carbohydrates and fat. Reputable fish feed manufacturing companies use fish protein from sustainable fisheries with all ingredients being fully traceable e.g. Skretting Fish Feeds. The fish used to make fishmeal and fish oil are typically small, bony and oily, such as sardines and anchovies. Fish species used in fishmeal are also typically short lived, productive and mostly come from sustainable fisheries (fishmeal does not normally originate from endangered line-fish fisheries). Human consumption of these types of fish is limited to around 10% of the total fishmeal/fish oil production (Anon 2004) suggesting that their use as a protein source for animal feeds means a more efficient utilisation of the resource. In addition approximately 25% of the global annual fishmeal production comes from fisheries waste (Jackson 2009).

Fish feed manufacturers are also increasingly using alternative protein sources such as vegetable protein (e.g. soya) and feather meal (finely ground chicken feathers) in their formulations. Depending on the species being fed, some producers have been able to supplement up to 40% of their protein requirements from these alternative protein sources (NOAA 2010). The use of intensive fish farming technologies also optimises food conversion ratios (FCR's) because one is providing as close to an ideal environment for fish growth as possible. No food is wasted.

The continual improvement of feeding practices will play an important role in increasing the economic efficiency of operating a fish farm. Consequently, improved feeding efficiencies help the sustainability of the world's fishmeal and fish oil supplies while still supporting the continued growth of aquaculture. Improvements, such as species-specific feed formulations, better pelleting technology, better feed distribution systems and better on-farm feed management have all contributed to reducing feed wastage and improving the food conversion efficiency of farmed fish. For example, the FCR of farmed salmon is reported to have reduced from more than 5.0: 1 in the early 1980s to its present level of less than 1.3:1 and, in some cases, to even less than 1.0:1 (weight of formulated pellets converted into wet weight of fish) (Tacon 2005). It has been estimated that the conversion ratio of wild fish into farmed salmon should fall to less than 1.5:1 by 2010 (Tacon 2005). Other figures quoted in the literature for conversion of wild fish to farmed fish vary from less than 300 g for fish such as tilapia and carp to between 2.5 - 3.7 kg for marine fish.

The proportion of dietary fishmeal and fish oil used in salmon feeds has dropped considerably over the past twenty years from around 60% fishmeal in 1985 to an around 30% today. On the other hand, fish oil has increased from 10% in 1985 to a high of around 40% in 2005 but has recently declined again to about 25% (Tacon 2005). Reasons for this were the increase dietary energy density (as fish oil is high in energy), which results in an increased growth rate and better food conversion by sparing protein for growth rather than using it for energy. As conversion ratios have improved over time, fewer kilograms of wild fish were needed to produce 1 kg of farmed fish for all species categories in 2004 relative to 1997, a trend which is expected to continue. Because of these improvements the aquaculture industry has grown tremendously in spite of the fact that the fishmeal supply has remained constant for the last decade. From 2000 to 2008 the amount of salmon produced had increased by 48 % but the total amount of fishmeal used only increased by 6.5 % (Jackson 2009). The latest research on salmon feeds have shown that a diet with only 8 % fishmeal can be used to grow salmon with similar results to a more conventional 22 % fishmeal diet (Skretting 2011).

While it may still be of concern that a conversion ratio of 1.5: 1 is still seen as 'wasteful' due to the skewed dependency on wild fish in producing farmed fish, under farming conditions there is a much more efficient conversion of lower trophic level (species lower in the food chain), lower value species into higher trophic level, higher value species. In addition to this, farmed fish use relatively less energy and can therefore use the protein in their food for growth rather than to provide energy to assist with escaping from predators, swimming against strong water currents etc. As a result, wild carnivorous fish tend to have FCRs higher than 6:1 (Sims 2004). In the South African context, preliminary calculations show (see Table 1) that Dusky Kob raised with an FCR of 1.2:1 while utilizing a 55 percent protein diet will require less than 2.1kg of wild anchovy to produce 1kg of farmed Dusky Kob.

Aquaculture consumes a large percentage of the world's fishmeal and most of the available fish oil. With aquatic carnivores' poor ability to utilise carbohydrates as an energy source, the pressure on the fish oil supply will remain for the moment (Beveridge 1999). Substituting fish oils with vegetable oils is possible in freshwater carnivores and omnivores. However marine fish require oils with high percentage n-3 highly unsaturated fatty acids which at present can only be derived in commercial quantities from fish oils. Efficient fish farming operations are achieving a 1:1 conversion of fish oil from feed to fish (Phillip Gatland, Selonda UK, pers. Comm..). What should also be considered is that in the unlikely event that the aquaculture industry stopped using all fishmeal and fish oil in their feeds, the available supply would be taken up immediately by the feedstuff industry for use in poultry, pig and (to a lesser extent) ruminant nutrition (New 2002).

Table 1: Wet anchovy : farmed kob conversion calculation estimates

Wet fish to dry fish protein conversion calculations:	
0.65	kg protein in 1kg fishmeal (Peruvian anchovy fishmeal - Shipp 2008)
4.5	kg wet fish gives 1kg fishmeal (Shipp 2008)
6.92	kg wet fish provides 1kg of dry protein
For 1 kg of 55% protein fish feed:	
2.86	kg of wet fish per kg fish feed (25% fishmeal from fishery by-products - Jackson 2009)
1.71	kg of wet fish per 1kg fish feed after 40% replacement of fish feed protein with soya, feathermeal etc (NOAA 2010)
2.06	kg of wet fish needed to produce 1kg of kob at an FCR of 1.2:1
Conclusion:	
2.06	kg of anchovy is needed to produce 1kg of farmed kob

Endangering Wildlife

Due to the fact that re-circulating culture systems are housed within a building, conflicts with wildlife are to a large degree eliminated.

Impacts on marine mammals are most often associated with sporadic entanglement in gear associated with cage culture aquaculture operations, causing injury and drowning. While published records are few, entanglements of dolphins in marine cage culture systems have been reported in Australia (Gibbs & Kemper, 2000; Kemper *et al*., 2003). Entanglement is a greater risk for small cetaceans such as short-beaked common dolphins and bottlenose dolphins. Entanglement risk is currently well-managed by the aquaculture industry in areas such as New Zealand where salmon farms exist, and there have been only three known cases of dolphin fatalities after becoming entangled in predator nets in over 25 years. Operational practices and net designs have improved such that entanglement should be a minor risk, however this will need to be monitored (Du Fresne, 2008). The entanglement of larger whales in aquaculture facilities are relatively rare events and are perceived not as important as other aquaculture-related problems.

There are considerable concerns about interactions with sharks and finfish cages and strategies are to reduce shark interactions with finfish farms, and to prevent mortality to trapped animals. Industry regards seal and sea lion interactions as a bigger problem than sharks. The main shark interactions involve mainly bronze whaler sharks and mako sharks, while whalers are a bigger problem for the yellowtail industry. While white shark interactions are rare (Malcolm *et al*. 2001) and the least likely to interact with farm operations (Bruce, 1998), though they generate much publicity, and are more difficult to handle because of the protected status of the sharks.

The main reason for these interactions are that sharks are attracted by (i) dead fish left in the pens; and (ii) effluent from the freezer boats associated with fish harvesting. Fish farms do not attract sharks to the region, but inadequate animal husbandry may increase the possibility of interactions with sharks in an area (Murray-Jones, 2004). The sharks typically break through the bottom of the nets, although occasionally they have been observed to break through the sidewall.

Although aquaculture cages do not appear to be attracting sharks to the region (Murray-Jones, 2004) the best preventative measures include: (i) the use of predator nets; (ii) reduce and remove the number of mortalities; (iii) siting of cages in relation to shark movements in order to minimise interactions; (iv) application of Shark Shield products to protect nets and staff; and (v) application of rigid cages. There is also a need for best practice guidelines and for data on interactions to be reported in order to determine the scale of the problem.

Predatory bird species are a principal problem for sea cage farming systems. Predatory birds can kill or wound fish, damage equipment, resulting in losses through escapes and stressed fish that results in reductions in growth and reduced resistance to disease. This in turn causes poor production and profitability. Cormorants (e.g. *Phalacrocorax carbo*), herons (e.g. *Ardea cinerea*) and shags (e.g. *P. aristotelis*) are the largest cause of problems; gulls (*Larus* spp.) less so. Many studies have shown that killing predatory birds is ineffective (Beveridge, 1988) as they are rapidly replaced by newly arriving individuals (Keller *et al.*, 1998). Moreover, it is usually illegal.

Exclusion devices such as top and curtain anti-predator nets work well with fish cages provided they are properly installed and maintained (Beveridge, 1996). Appropriate mesh size must be chosen and curtain nets installed at a sufficient distance from the cage bag that predators cannot reach the caged stock. The nets must be kept taut as birds rapidly learn that poorly tensioned nets offer little protection to fish. Effective anti-predator exclusion devices for cages can prove expensive to install and maintain and increase working difficulties for farm staff.

Small cetaceans (dolphins) and pinnipeds (seals) are the primary candidates for entanglement in marine cage farming systems. The entanglement of cetaceans in fishing gear is a well documented phenomenon, resulting in some 300,000 cetacean mortalities per year (Read *et al*. 2006). In comparison there are relatively few documented instances of cetacean and pinnipeds entanglement in marine farms and it is generally accepted that provided farms are well maintained, the risk entanglement is probably low (Lloyd, 2003). There are very few reported large cetacean (whales) interactions with finfish farms (Kemper & Gibbs 2001; Kemper *et al*. 2003).

In general, entanglement risk can be minimised by enclosing predator nets at the bottom; keeping nets taut; using mesh size <6cm; and keeping nets well maintained (e.g. repairing holes immediately). The risk of entanglement of marine mammals in predator nets in general is considered as low (Du Fresne, S., 2008). Reducing feed waste as much as possible will also limit fish aggregations near farms.

Some wildlife is influenced positively by cage aquaculture. Felsing *et al*. (2005) found that the abundance of wild fish around aquaculture sites increase due to the increased food availability in the form of aquaculture waste. Not all waste escaping from the cages will settle down on the bottom as up to 80% of the organic waste can be consumed by wild fish (Vita *et al*., 2004).

In the event of large marine vertebrates becoming entangled in the cage system, experts from the local aquarium, university and nature conservation will be contacted to aid in the rescue operation.

Social Concerns

Both land-based and sea-based fish farming activities are well suited for creating jobs and sustaining livelihoods and environments in peri-urban and non-urban areas. As a result, marine aquaculture is seen as an area of investment by governments seeking to sustain and upgrade rural communities.

In some countries (e.g. New Zealand) establishment of sea farms has been resisted by local coastal communities as they are considered to “spoil” the aesthetics of seascapes (Mike Stobbard, NIWA, pers. comm.).

Animal Welfare

It is in the interests of marine aquaculture operators to take every step to safeguard the health and welfare of the animals in their care. Healthier animals grow faster and have a more resilient immune system (i.e. they do not contract diseases). It is in the farmer’s interests that water conditions are of sufficient quality and quantity to ensure that the health and well-being of the cultured species is properly maintained. Healthy fish in a marine aquaculture operation should show minimal signs of sickness or injury and bio-security measures should be put in place to minimize disease transfer risk.

It is in the farmer’s interest to adjust animal stocking densities to meet the holding capacity of the system and environment in which the species is cultured, to provide for the health and behavioural needs of the species as well as the availability of an adequate oxygen supply, available space and for the assimilation of waste products.

It is in the farmer’s interest to look after his fish. Poor growing conditions cause stress or toxic effects on the fish and reduce the farms productivity.

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