Environmentally Sustainable Salmonid Culture

Yusuf GÜNER
Ege University, Faculty of Fisheries, Aquaculture Department, Izmir-Turkey
yusuf.guner@ege.edu.tr

Gürel TÜRKMEN
Ege University, Faculty of Fisheries, Aquaculture Department, Izmir-Turkey
gurel.turkmen@ege.edu.tr

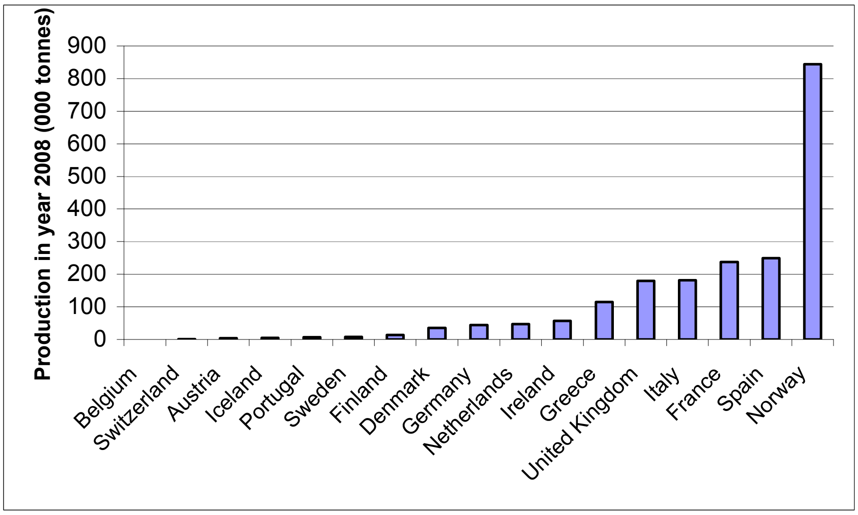
Abstract: Until very recently most research relating environmental quality and aquaculture was limited to assessment of environmental conditions necessary for culture. Emphasis was placed on dissolved oxygen requirement of the culture fish or the maximum dissolved nitrogen level that could be tolerated without impairment of growth rates or survival. Most attention was directed towards the effect of the environment upon the aquaculture operation, while the converse perspective, the effect of aquaculture upon environmental quality, was largely ignored. The sustainability of aquaculture development and the environmental impacts of aquaculture operations have become a matter of considerable concern for all stakeholders. The development of the aquaculture industry, especially if it is to sustain its current growth, depends on finding ways to increase its environmental, economic and social acceptability. The technique used to culture salmonids throughout the world varies greatly with respect to the water source and means of confining the fish. With the rapid growth of salmonid cage culture over the past decade has come increased examination of this industry segment as a potential pollution source. Aquaculture pollution mainly originates from the physical and chemical characteristics of feed and the applied feeding management. This article reviews the available information on those environmental impacts of salmonid culture and three reportedly environmentally-friendly alternatives; a marine floating bag system; a land-based saltwater flow-through system; and a land-based freshwater recirculating system.

Key words: Salmonid, Aquaculture, Environment

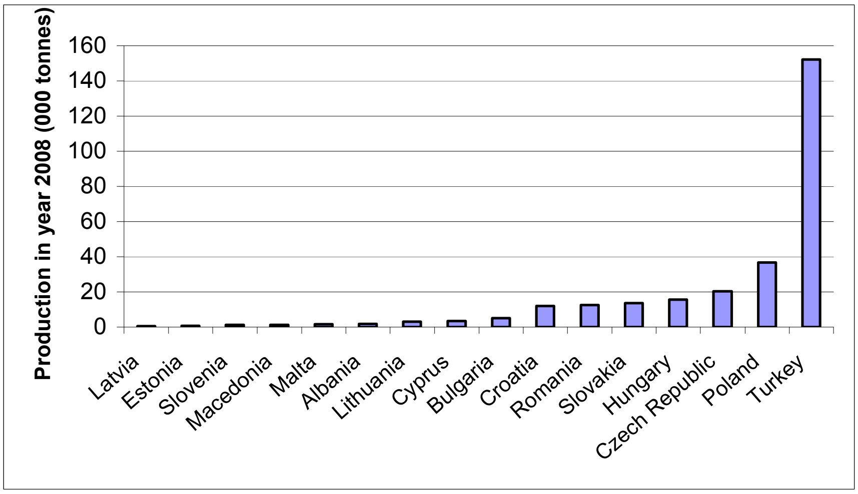
1. Introduction

Aquaculture has been the most important food source in the world, as an alternative to land based agriculture. The FAO records indicate this industry as the fastest growing sector in agriculture. The production amount had increased from 16.8 million metric tonnes to 68.35 m metric tonnes between 1990 and 2008. (FAO 2010) Based on these statistics, aquaculture is growing more rapidly than all other animal food-producing sectors. Aquaculture production in Europe has grown to become a significant industry over the past decade and has partly compensated for the decrease in capture pro duction due to dwindling natural stocks (European Commission 2002). The largest aquaculture producer in Europe in 2008 was Norway (Fig. 1). In terms of volume of production there are four other countries in Western Europe, aside from Norway, which are major producers, namely Spain, France, Italy and the United Kingdom. In Eastern Europe, in terms of volume of production, Turkey is the major producer (Fig. 1; Fishstat 2010). The most important species in terms of volume and value of production for aquaculture is the Atlantic salmon (Salmo salar) (high market value but also high cost of production), while the species with the second highest levels of production are mussels (in terms of volume) and seabream and seabass (in terms of value) . It seems that high production (volume and value) is associated with intensive farming of marine fish species (salmon, while the highest production purely in terms of volume (i.e. mussel farming) is associated with lower market value.

Of the total world aquaculture production in 2008, 43% was in the form of finfish and crustacean species, the production of which is dependent upon the supply and use of external off-farm nutrient inputs in the form of compound aquaculture feeds. Feed development may need to place increased emphasis on the efficient use of resources and the reduction of feed waste and nutrient discharge. The technique used to culture salmonids throughout the world vary greatly particulary with respect to the water source(i.e., groundwaters or fresh, salt or brackish surface waters) and the means of confining the fish (i.e., raceways,tanks,ponds,cages). Land-based culture vs. cage culture in open water is a major dichotomy central to the prediction of likely environmental impacts. A wide variety of waste recovery or treatment techniques are available to the land-based culturist where effluent is confined within some form of conduit.In cage culture the effluent is immediately diluted within the receiving water body with little or no opportunity for waste recovery and treatment. A land-based salmonid farm is generally viewed by regulators as a typical point-source discharge.It will often be required to have some means of waste retention or treatment (e.g.,settling pond or filtration), and the effluent will be regulated for parameters such as total suspend solids (TSS) and biochemical oxygen demand (BOD). However, a cage farm is subject to none of these treatment or effluent limitations, even if it contains as great or greater fish biomass as its land-based counterpart. This article reviews the available information on those environmental impacts of salmonid culture and three reportedly environmentally-friendly alternatives; a marine floating bag system; a land-based saltwater flow-through system; and a land-based freshwater recirculating system.



A (Western and Central Region of European Aquaculture)



B (Eastern Region of Europaen Aquaculture)

Figure 1. European aquaculture production (FAO, 2010).

2. Types of Wastes Associated with Salmonid Culture

2.1. Particulate Wastes

The primary types of particulate waste from salmonid culture are feces and uningested feed pellets.When fed a dry pelleted diet, salmonid feces typically comprise about one-third of ingested material on a dry weight basis (Butz and Vens-Cappell 1982). The amount of uningested feed will depend upon many factors, including the feed type and metod of dispersal, so consequently estimates of feed wastage vary greatly. Between 1 and 40 % of the feed provided to the fish will not be ingested. Such methods have shown that food losses are typically 1–15%, although if feeding with trash fish they can be as high as 40% (Wu 1995). Feed pellets may be rejected by the fish rather than swallowed if they are contaminated in any way or the fish does not feel like eating (Smith et al. 1993). There is some evidence that feed waste is lower in land-based systems than in cages, possibly due to more efficient feeding in tank sor pond (Beveridge 1987).

2.2. Nitrogen and Phosphorus

Pelleted salmonid feed typically 1-1.5 % phosphorus. The phosphorus in most feeds is both in exceess of the dietary needs of the cultured fish and partially in an unassimilable form. Consequently, a substantial fraction of the phosphorus provided is lost to the environment via the feces, in addition to lesser amounts excreted in the urine. Ammonia and, to a lesser extent, urea are the principale nitrogenous wastes associated with fish culture, anda re produced as by products of protein metabolism. Ammonia may be present either as the non-toxic ammonium ion (NH^+_4) or as the toxic un-ionized form (NH_3). The relative pproportions of the two form are dependent upon temperature and pH, with formation of the toxic NH_3 favoured by high temperature and high pH. No cases of ammonia toxicity to aquatic life downstream from fish farm have been reported. Nitrogen and phosphorus are recognized as limitin nutrients in many aquatic systems. The addition of these nutrients generally results in an increase in plant growth.

2.3. Dissolved Oxygen Depletion

Salmonid culture will reduce dissolved oxygen concentration through both fish respiration and mineralization of the organic-rich wastes(i.e., feed, fece, soluble metabolites). Salmonid rspiration rate depends upon fish, age, sex, activity and temperature, but an average respiration rate for routine metabolism is about 300 mg O_2/kg wet weight/h (Kils 1979). The BOD of the feces and metabolic wastes may consume about 1.5-3 times as much oxygen as respiration alone (Willoughby et al. 1972). Effluent released from salmonid farm can deplete dissolved oxygen in receiving water, either because the effluent itself is oxygen depleted, because of its high BOD, or a combination of both factors. There is also the possibilty of indirect effects, such as nutrient-induced growth of micro- or macroalgae, and the eventual oxygen depletion accompanying decomposition of this algal biomass.

2.4. Chemotherapeutants

Chemotherapeutants are employed to treat viral,fungal,bacterial or parasitic infections of culture salmonids.The most commonly used parasiticide/fungicide in salmonid culture is formalin. A wide variety of antibiotics are administered as feed supplements to treat bacterial diseases in salmonids. On a worldwide basis, oxolinic acid and oxytetracycline have historically comprised the vast majority of total antibiotic use by the salmonid culture industry, although their use has diminished in recent years. Other antibiotic used in one or more salmonid-producing countries include potentiated sulfonamides, flumequin,chloramine T, and erythromycine. Little is known about the environmental fate and effects of salmonid chemotherapeutants despite the fact that a substantial portion of the drugs often leave the culture site via the effluent,or in the case of cage culture, are directly released to the environment. Regulatory agencies have generaly assumed that rapide dilution of the therapeutant would result in little or no environmental impact.

3. Environmental Impacts of Land-Based Facilities

Land-based salmonid culture systems in freshwater include hatcheries, systems for the production of fry and smolts, and systems for growth to consumption or restocking size. Following this early stage, salmonids may be grown using a variety of land-based or cage.Land-based sysrems include tanks, earth ponds and raceways. Such systems typcally are of the ‘flow-through’ type, but some ‘recycle’ systems are also in use. Recycling systems are used in fish farming when water availibity is limited, or there is a need for strict control over the culture environment. The high cost of recycling systems has restricted their use in salmonid culture to a few hatcheries that heat water to accelerate egg development and then recycle the water to conserve heat.

3.1. Waste Products and Loading

Uneaten feed and excreta give rise to elevated concentrations of suspended solids, BOD, nutrients and minor elements in land-based salmonid farm effluent. Many studies show considerable variation in waste loading, attributable to differences in species, fish size, physiological status,method and intensity of culture, and temperature. Waste loading from hatcheries are likely to be small during egg incubation because there is no feeding. After hatching, use of artificial feed results in increasing waste loading from discharge of uneaten pellets,feces and soluble excreta. Following early growth stage, salmonids will be transferred to different grow-out systems,the type of which affects total waste loading. During winter, when shorter day length and lower water temperature limits activity and feeding, wastage rates fall dramatically. On a daily basis, waste loading vary depending principally upon feeding schedules and tank, pond or raceway cleaning. Suspended solid, BOD and total phosphorus commonly peak during and immediately after feeding, later followed by peak ammonium concentration. A number of studies reviewed in Alabaster (1982) reveal a net reduction in solids concentration as water passed through the farm. However, accumulation of solids in pond and tanks can lead to very high “shock” loads of solids during harvesting or tank cleaning.

3.2. Environmental İmpacts

3.2.1. *Water* Use: Water requirement forland-based salmonid culture depend on stock biomass and feeding patterns.Withdrawal of water for land-based salmonis farm has the potential to reduce water flow from streams and rivers, with potetial impacts including: (1) changes in channel shape, patters of sedimentation, water movement and silation; (2) loss of spawning areas for fish stocks, or loss of nursery areas; (3)barriers to the movement of migratory fish; (4) changes in biological communities, through loss of dilution capacity between inflow and outflow, reduced turbulence and oxygenation,plus possible loss of habitat due to stranding and desiccation in channel areas above the waterline.

3.2.2. *Dissolved Oxyge*n: A survey of effluent from land-based tank and pond farm by Alabaster (1982) found a mean decrease of 1.6 mg/l. from inflow to outflow, with an average flow of 12.6 $ls^{-1}.t^{-1}$ of annual fish production. Depending on the quality of the effluent, further changes in dissolved oxygen in receiving water may occur. The need to maintain oxygen levels to protect the farm stock shoukd ensure that significant depletion downstream from farm is unlikely in most cases, although the possibility exists of some localized depletion associated with deposition of organic solids.

3.2.3. *Chemotherapeutants*: Toxicity to downstream biota attributable to discharge of waste chemotherapeutants is possible, although there is little information on such effects. Formalin and Iodophors are the most widely used disinfectants in European aquaculture (Henderson and Davies 2000). Antifoulants are, by their nature, toxic to marine organisms. The amounts involved may be substantial-for example, around 156 tonnes of copper were released into the environment from the use of antifouling treatments in salmon farming in Norway in 1994. Formalin is widely used asan immersion treatment on tank, pond and cage farm for control of ectoparasites,usually as a bath treatment at 150-250 mg/l. for 1 h. lethal concentration of formalin vary from 60-600 mg/l. for fish (for exposures of 24-96 h.), 0.3-0.5 mg/l. for alg, to up to 835 mg/l. for certain aquatic insects, suggestion the possiblity of some localized toxic effects on aquatic biota directly below land-based outfalls, particulary for the more sensitive planktonic and microbial organisms.

3.2.4. *Microorganisms*: Some qualitative changes in the bacterial microflora of trout farm effluents have been observed, altough the bacteria present are generally similar in terms of number and composition to those found in the inflows (Austin 1985). Although some studies have shown increases in the number of fecal coliform during the passage of water through trout farm (Hinshaw 1973), the data are fragmentary and the consensus seems to be that this phenomenon is not a significant problem. Viruses have also been detected in farm effluent. Leon and Turner (1979) measured effluent concentrations of infection hematopoietic necrosis virus (IHNV) as high as 400 plaque-forming units (pfu) ml^{-1} during a disease outbreak at a salmonid hatchery.

3.2.5. *Benthic Impacts*: Impacts of fish farm wastes include a loss of sensitive invertebrate species at or just below the point of discharge, with an increase in the density and biomass of organisms tolerant of organic pollution such as olgochaetes, chironomids and certian leeches. Markmann (1982) also reporteda loss of ‘clean-water species’ such as Plecoptera, Ephemeroptera and Trichoptera and an increase in oligochaetes, leeches, Diptera larvae and gastropods below Danish rainbow trout farm. Organic-rich particulate wastes appear to be the most significant source of impact and there is evidence that benthic communities can return to background condition if suspended solids are removed from effluent (NCC 1990).

3.2.6. *Macrophytes*: Publised data on the effects on land-based farm on macrophytes are limited, although enhanced macrophyte growth, particularly growth of pollution-tolerant species, is frequently cited as a response to fish farm discharge in English rivers. Studies on the River Hull show greater adventitious root growth and shoot extension in *Ranunculus penicillatus* var. *Calcareus* collected below a trout farm discharge,although effects related to weed cutting may also have been important (Carr 1988).

3.2.7. *Wild Fish Populations*: Water withdrawal for land-based tank or pond farm may result in physical and chemical changes to fish habitats, and some loss of habitat has been reported in England (Allan 1983). However, studies in Denmark (Rasmussen 1988) and the U.S. (Hinshaw 1973) showed that addition of fish farm effuent may increase the productivity of downstream fish populations.

4. Waste Reduction and Treatment

4.1. Feeding Techniques and Feed Type

Uneaten food, faecal losses, food conversion ratios (FCR; the ratio of the weight of feed added to the weight of fish produced) and digestibility can be estimated to derive expressions of various wastes, such as for N or P. The result is a budget showing the flow of nutrients from the food offered, the assimilation of food in the fish as a result of growth (metabolism) and the loss of nutrients into the sediments and water column. Wastage of whole pellets may depend on various factors. If pellets are supplied at a rate that exceeds the ability of the fish to eat them or under conditions such that the pellets are not detected as they settle, there will be wastage of whole pellets. Davies (2000) reported predicted dissolved N release rates in the range of 35–45 kg per tonne of salmon produced, depending on the details of the stocking, feeding and harvesting strategies adopted. GESAMP (1996) reported values for the rate of excretion of dissolved N by farmed fish of around 75–120 kg N/tonnes of production. If the FCR, wastage from uneaten pellets and indigestibility can be reduced further, it is anticipated that release rate of dissolved N would be reduced to 33 kg/tonne of production (Davies 2000). Further reductions need new technology and additional innovative approaches. Careful feeding and the use of correct diet offer good potential to reduce effluent loads at the source. Overfeeding of fish also decreases feed digestibility and increases fecal production. Thus, a reduction in feed losses by monitoring of feed losses and careful hand-feeding, either exclusively or as a supplement to automatic feeders, can significantly reduce effluent loads and reduce impacts on running waters (Bromage et al. 1990).

The physical characteristics of the fish food are very important in term of pollution potential of the feed. The use of dry pellets rather than moist pellets or"trash" or "rough" fish considerably reduce the amount of wastage (Alabaster 1982). Unstable pellts may also increase waste loading if rapidly broken down into unacceptably small-size particles. Foof with low settling velocity also help to prevent excess wastage. The amount of phosphorus discharge from fish farm is determined by the amount and digestibility of phosphorus in the feed (Crampton 1987). The total concentration of phosphorus must be kept low and its digestibility high to minimize waste phosphorus release. Most waste phosphorus is bound in the particulate fraction, although a significant part of this particulate fraction is easily dissoveld. In the marine environment, losses of P from fish farms have been estimated as 19.6–22.4 kg/tonne fish (trout) produced, 34–41% of which is released in dissolved form with the remainder lost by sedimentation. Holby and Hall (1991) estimated that 4–8% of the sedimentary P was returned to the water column per year. There would thus seem to be excellent potential for reducing phosphorus levels in salmonid farm effluent by reducing phosphorus in feed.The level of protein and amino acid balance has been determined (decreased N content in the feed, 45% protein in the feeds), and the P content in the feeds has been decreased (from 1.5 to 0.7 in salmon feeds). Nitrogen excretion depends on many factors including its bioavailability and feeding rate, but on average, 60 % of dietary nitrogen is excreted (Beamis and Thomas 1984)The quality of fish meal and other protein sources used in the diet dictates the proportion of feed protein that can be assimilated into muscle tissue.Ammonia excretion rates are higher if protein is used as energy source, because ammonia is a by-product of protein metabolism. Poor quality carbohydrate sources result in increased suspended solids and BOD and can cause growth of sewage fungus in receivingwaters. Alternatively, if the carbohydrate(or lipid)source is insufficient, then ammonia and other nitrogenous wastes increase. In the production of extrude pellets, the higher temperatures and pressures may result ingelatinization of dietary starch, thus increasing the bioavailability of carbohydrate. Alternative protein sources to replace fishmeal (e.g. soya) and methods of reducing the discharge of feed from farms have been examined (Hardy 1996). Although carbohydrates can be used as an alternative to fishmeal, research has shown that certain fish, such as rainbow trout (*Oncorhynchus mykiss*), use dietary carbohydrates rather poorly: they show prolonged postprandial hyperglycaemia. The efficiency of glucose utilization as an energy source by rainbow trout is low (Panserat et al. 2000). Further research is needed to understand dietary carbohydrate utilization in fish in order to enable the development of diets that can replace fishmeal as the major source of dietary protein for farmed fish. Recently, a reduction in N released to the environment was achieved through a general reduction in FCR, which is currently 1:1 for salmon farming in Western Europe (Pearson and Black 2001). Oil and fats may contribute to visible surface scums and the BOD of fish farm effluent. Problems associated with these constituents can be partly avoided by the use of high quality ingredients and a correct balance between requirement and concentration in the diet. Many freshwater diets are formulated as “high energy” diets that contain high level of fat.Thes diets are designed to minimize protein metabolism and can be used to reduce ammonia excretion.

4.2. Settlement Treatment

Settlement treatment work on the principal that solid particles with a densiity greater than water will fall out of suspension when water fow is reduced.the rate at which particles will setle in stil water condition depens largely on particle size and density; larger or more dense particles will settle more rapidly than smaller or less dense ones. The design and effectiveness of a settlement system is therefore dependent on the retention time of effluent in a settling tank or pond as well as the surface area available for settling. It is also desirable to prevent the solid in the effluent becoming fragmented as particle break up will inhibit settling and promote leaching of nutrient from the solid waste. Fish farm and settling tanks sholud be designed to minimize break up due to unnecessary turbulance.The stuidies show that up to 90 % of suspended solids, 60 % of BOD and 50 % of total phosphorus loads can be removed by settlement treatment, although system performance is extremely variable. When level of suspended solids are <10 mg/l., is common in salmonid farm effluent, efficiency is greatly reduced, although it is possible for suspended solids to be increased by pre-concentration treatment.It is also difficult to obtain suspended solids levels of < 6 mg/l in settled effluent (Henderson and Bromage 1988). Other problems are that the area required for settling ponds or lagoons can be large in comparison with the size of the farm. Others class of settling tank desing are based on a circular water flow (centrifuge) and the swirl concentrator . A major constraint upon the use of settlement devices remains the characterization of particle size of loads; as previously mentiond, both the nature and quantity of wastes produced by a farm varies substantially both during a day, and throughout the growing season. A consequnce of this varying waste output is that in order for settlement devices to be effective waste treatment systems,they must be designed to operate efficiently over a wide range of partile sizes.

4.3. Screening and Filtration Treatment

The most popular method of mechanical particle separation is the treatment by static or rotating microscreens. The treatment efficiency of microscreens has been tested in several studies (Lekang et al., 2000; Makinen et al., 1988; Wedekind, 1996) and a wide range of nutrient removal could be found. By using microscreens, reduction of solids achieved 50 – 74%, 49.3 – 63% of total phosphorus (TP) and 10– 42.7% of total nitrogen (TN). Salmonid farm effluent may be treated by passage through a screen to remove particulate matter. It is a self-cleaning or rotating filter. The most common configurations are variation of rotary screens, where the screen operates only partially submerged in the water that is to be filtered. The submerged section of the screen filtes the water passing through it while the remainder of the screen is cleaned, usually by a high pressure water jet, with the residue running to a settling pond. The clean section of screen then rotates to replace the submerged section. One of these systems are the “Triangelfilter”. Its removal efficiencies data clearly demostrate the potential of these and similar screen filters for removing materials from fish farm effluent. The advantage of the “Triangelfilter” or similar systems is that solids are separated from the effluent water relatively quickly, thereby reducing the amount of time for leaching of soluble material from solid particules. After screening, filtration may be used as a secondary systems for fine solids removal. Diatomaceous earth filters are good at removing extremely fine particulate matter (0.1-5 µm), but are not cost effective in treating effluent from salmonid farm. The most common filter medium is sand and gravel ranging in size from 0.25-5mm, usually graded coarse to fine in the direction of water flow. The growing concern over potential impacts of therapeutants on the environment has stimulated interest in techniques for removing such chemicals from fish farm effluent. But there is little information on methods for treatment of chemical.

4.4. Biofiltration

Biofiltration can, in theory, be used to improve effluent water quality from salmonid farm. In aquaculture, biofiltres are commonly used in recycle sytems to prevent accumulation of ammonia and nitrite.The technique is not considered practical or economic for treatment of salmonid farm wffluent in most circumstances due to low temperatures (NCC 1990) and large volum of effluent involved. There has been some interest in using algae and aquatic macrophytes, such as reeds, to reduce levels of nutrients in effluent. Reed beds are being investigated for nutrient removel from small scale sewage works and water hyacinths and duckweed have been grow for this purpose in warmer countries (Zirschky and Reed 1988). As with settlement pond, one of the major constraints to biofilters is that of space required.

4.5. Constructed Wetlands

Constructed wetlands represent a natural treatment system based on biological symbiosis between macrophytes (*Phragmites sp., Typha sp*., etc.) and microorganisms (bacteria, fungi, algae), and their interactions with the soil chemistry. In recent years, created wetlands have been developed to successfully treat agricultural, municipal, or industrial wastewaters. Depending on the choice of construction and function, macrophyte treatment systems can be divided into:

1. ponds with free-floating or submersed plants and no effluent; percolation through the soil
2. root zone systems with emergent plants and completely effluent percolation through the soil;
3. hydrobotanic systems as link between (1) ponds and (2) root zone systems.

Moreover, these treatment systems can be subclassified by the flow direction of effluents (vertical or horizontal), the plant species or type of soil (Kehrer, 1997). Biotic and abiotic purification mechanisms of constructed wetlands are based on the following processes (Gumbricht 1993): (a) mechanical screening and sedimentation, (b) microbial degradation, (c) biochemical nutrient removal of plant rhizomes, (d) adsorption through ligand exchange, (e) precipitation and chemical fixation of reactive soil ingredients.Removal efficiency is strongly influenced by the microorganisms inhabiting soil particles and the rhizome of plants. Plants with aerenchym root systems aerate the soil and consequently aerobic microorganism (e. g. Nitrosomonas sp., Nitrobacter sp.) growth is promoted. Bahlo and Wach (1993) found more intensive biological degradation of ammonium to nitrate close to the rhizomes. Microbial elimination of nitrate – nitrogen (denitrification) occurs in the anaerobic parts of the soil, which can be found even in effluents of constructed wetlands with oxygen levels of more than 4 mg/l. Particle bound phosphorus is mineralized by heterotrophic microorganism and at low redox-potential sorpted to iron-, aluminium-, manganese hydroxides/-oxides, calcium or clay minerals (Gumbricht, 1993). Removal processes of constructed wetlands show increased efficiency by using smaller soil particle sizes.

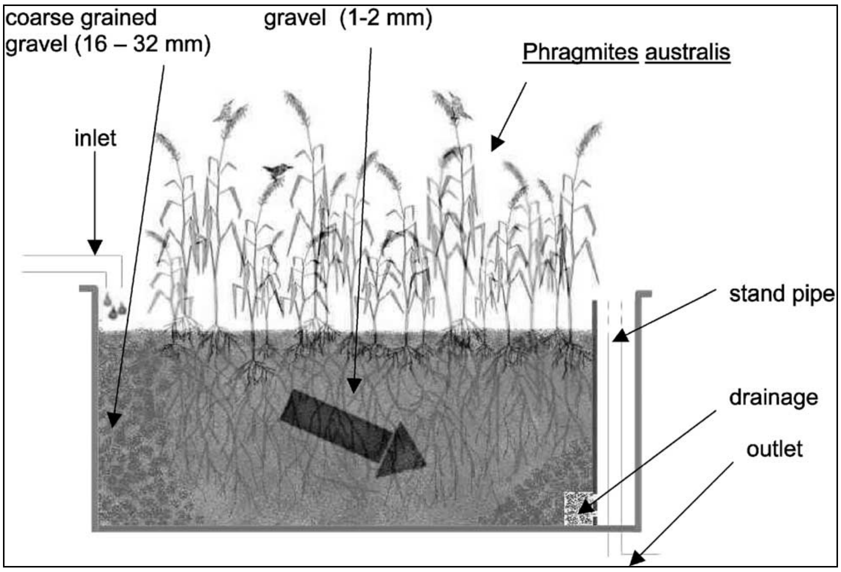


Figure 2. Design of used root zone constructed wetlands with horizontal flow and emergent plants; larger substrate at inlet and outlet to facilitate influent distribution and effluent drainage (Schulz et al. 2003).

Schulz et al. (2003) investigated treatment of aquaculture effluents of flow- through systems in created wetlands. The constructed wetlands types used in this study were subsurface root zone systems with emergent plants and horizontal effluent soil percolation (Fig.2). Three 1.40 x 1.00 x 0.70 m (L x W x H) root zone systems were filled with sands of 1 – 2 mm particle size and planted with 20 rooted shoots of reed per square meter (*Phragmites australis*). Nutrient removal of rainbow trout (*Oncorhynchus mykiss*) effluents flowing through the wetland was determined for hydraulic loading rates of 1, 3 and 5 l/min corresponding to very short hydraulic residence times (HRTs) of 7.5, 2.5 and 1.5 h, respectively. Inflowing nutrients were removed within every continuously flooded wetland. Total suspended solids (TSS) and chemical oxygen demand (COD) were reduced by 95.8 – 97.3% and 64.1 – 73.8%, respectively, and demonstrated no influence of HRT. Total phosphorus (TP) and total nitrogen (TN) removal rates varied from 49.0% to 68.5% and 20.6% to 41.8%, respectively, and were negatively correlated with HRTs. Effluent purification was best at HRT of 7.5 h, but sufficient removal rates were achieved for shorter HRTs. Obtained removal rates demonstrated that created wetlands with high hydraulic loads reduced inflowing nutrients by amounts comparable to, or exceeding that achieved by mechanical treatments such as microscreens or sedimentation tanks. Thus, created wetlands are a viable alternative treatment for aquaculture effluents.

4.6. Integrated Aquaculture

The salmon aquaculture industry has adopted a number of strategies to reduce nutrient wastes and its impacts on the local environment, including improved feed formulations and digestibility, improvements in feed/waste monitoring and feeding techniques, site rotation and fallowing, and reduced stocking densities. Integrating the culture of filter-feeding bivalve molluscs (e.g. mussels, oysters, scallops) with salmon farms has long been advocated as another potential strategy to alleviate waste loadings and environmental impacts associated with open-water salmon culture (Folke et al., 1994; Kautsky et al., 1997). In a conceptual open-water integrated culture system as proposed by Kautsky et al. (1997), filter-feeding bivalves are cultured adjacent to meshed fish cages, reducing nutrient loadings by filtering and assimilating particulate wastes (fish feed and faeces) as well as any phytoplankton production stimulated by introduced dissolved nutrient wastes. Waste nutrients, rather than being lost to the local environment, as in traditional monoculture, are removed upon harvest of the cultured bivalves. With an enhanced food supply within a fish farm, there is also potential for enhancing bivalve growth and production beyond that normally expected in local waters. Therefore, integrated culture has the potential to increase the efficiency and productivity of a fish farm while reducing waste loadings and environmental impacts. This model of integrated bivalve – fish culture is certainly simple and, intuitively, appears promising. However, few practical studies have been undertaken, with conflicting conclusions regarding the potential for open-water integrated culture to enhance bivalve production and, by implication, to significantly reduce fish farm wastes. Studies have shown that bivalves are capable of utilising fish farm wastes as an additional food supply (Mazzola and Sarà 2001), likely explaining the increased growth displayed by mussels (Wallace, 1980) and oysters (Jones and Iwama, 1991) grown adjacent to fish cages. However, other studies have reported no, or minimal, growth enhancement of bivalves cultured in an integrated bivalve – fish system (Gryska et al.,1996).

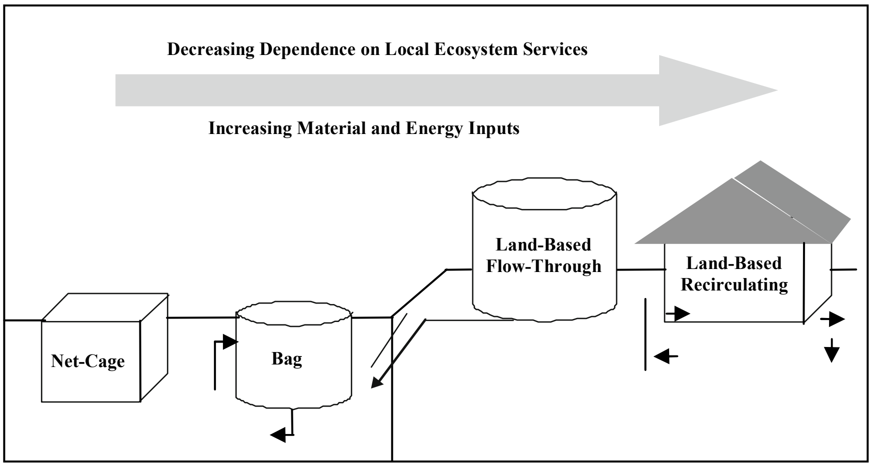


Figure 3. The flow of material and energy inputs in relation to the dependence on ecosystem services

4.7. Land-Based Recirculating Systems

In recent years, particular emphasis has been placed on the development of closed-containment systems, a term widely used to describe a range of production systems that employ an impermeable barrier to isolate the culture environment from surrounding ecosystems. Theoretically, by culturing fish in a closed environment, fish farmers can exert greater control over the rearing conditions, allowing them to improve the quality of the fish while at the same time reducing proximate environmental impacts. Some of the potential advantages of closed-containment systems are: (1) minimized fish escapes; (2) minimized predator interactions; (3) reduced disease transmission; (4) lower feed inputs; (5) higher stocking densities; and (6) improved waste management capabilities. The system is entirely contained inside a warehouse and consists of a series of circular concrete tanks of various sizes. New water is continuously pumped into the tanks from an on-site freshwater well. Approximately 99% of the water is recirculated back into the system after passing through an extensive mechanical and biofiltration process.Wastewater that is lost from the system at various stages passes through a holding tank where solids are settled out and the remaining wastewater enters the municipal sewer system. The solid fish wastes are collected in the holding tank for future use as a substitute for conventional synthetic fertilizers for plants fertilizer in an adjacent greenhouse. Ayer and Tyedmers (2008), studied on Assessing alternative aquaculture technologies: life cycle assessment of salmaonid culture systems in Canada. In the study, four different system such as; Marine net-pen, Marine floating bag, Land-based flow-through and Land-based recirculating were studied. At the end of study, the recirculating system was the only system at which wastes were managed. The differences of the systems was presented in Fig. 3 (Ayer and Tyedmers 2008).

5. Conclusions

Intensive salmonid cultivation can introduce significant quantities of nutrient wastes from uneaten feed, faeces and excretory products into the local environment. Along with the growth of the salmon aquaculture industry, so too have concerns regarding the environmental impacts from aquaculture wastes. One of the major challenges for the sustainable development of salmonid culture, and the aquaculture industry generally, is to minimise environmental degradation concurrent with its projected expansion. The impacts of particulate wastes such as uneaten fish feed and faeces are largely on the benthic environment immediately surrounding fish farms; alterations to sediment biogeochemistry and benthos from sedimented solid wastes are well-documented (Brooks et al., 2003). Remineralised nutrients from these deposits, along with fish metabolic wastes, particularly ammonia, are dispersed within the receiving water body and may contribute to localised hypernutrification. During seasonal cycles of nutrient availability, additional dissolved nutrient wastes have the potential to stimulate benthic algal production, increase phytoplankton production leading to localised eutrophic conditions, and alter dissolved N/P ratios that promote the growth of toxic algal species (Folke et al., 1994). Bubridge and Burbridge (1994) identify three ways in which it would be possible to achieve control of feed impacts from aquaculture: (1) control of the sites where the culture farms are located; (2) control of the released effluents; (3) monitoring of impacts generated by effluents once the farm begins its work. Polyculture, or inte- grated aquaculture associating shellfish and algae culture with fish culture may be part of the solution (Cheshuk et al. 2003). The development and application of Environmental Quality Standards (EQS) and the design of models for evaluating environmental impacts are other initiatives for controlling and monitoring the environmental impact of fish farms.

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