The scientific basis of marine fish farm regulation

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ABSTRACT

As aquaculture expands, regulation to prevent environmental damage is an essential requirement for sustainability. In this paper, we discuss three aspects of aquaculture regulation pertaining to 1) protection of other resource users, 2) protection of ecosystem structure (conservation), and 3) protection of ecosystem function (recycling). Some of the approaches taken to regulation of aquaculture in several countries are presented, emphasizing the need for these to be based firmly in a good scientific understanding of the ecosystem and the processes by which it interacts with aquaculture.

INTRODUCTION

Marine fin-fish aquaculture continues to expand, although expansion has to some extent, plateaued in several of the developed countries, where modern intensive aquaculture was pioneered. For example, in Scotland, production increased steadily reaching a peak in 2003, but has since been variable (Fig. 1). There are several reasons for this, including disease and market conditions, but one reason has been constraints placed on farmers by planners and regulators. Planners must ensure that aquaculture developments meet aesthetic, social and economic criteria, and that there is harmonization between new developments and local infrastructure capacity or other resource use e.g., tourism. Planners and regulators have duties to ensure that developments do not adversely affect the environment. The objectives of regulation can be separated into three areas:

1. protection of legitimate users of the environment, such as tourists or fishermen, such that resources are fairly distributed;
2. protection of the environment for its biological structure including protection of important/rare habitats and species; and
3. protection of ecosystem functions such as the recycling of nutrients and the maintenance of oxygen levels.

The first of these is the subject of the evolving "discipline" of Integrated Coastal Zone Management (ICZM) which has eight broad principles (DEFRA, 2006). It is worth presenting these here in full:

a. A broad holistic approach

The objective of a holistic approach is to forego piecemeal management and decision making in favor of a more strategic approach, which looks at the 'bigger picture', including cumulative causes and effects. This means considering the conservation value of natural systems alongside the human activities which take place on land and coastal waters.

Taking a holistic approach will also involve looking at the problems and issues on the coast in the widest possible context, including looking at the marine and terrestrial components of the coastal zone and considering how different issues conflict or interact together.

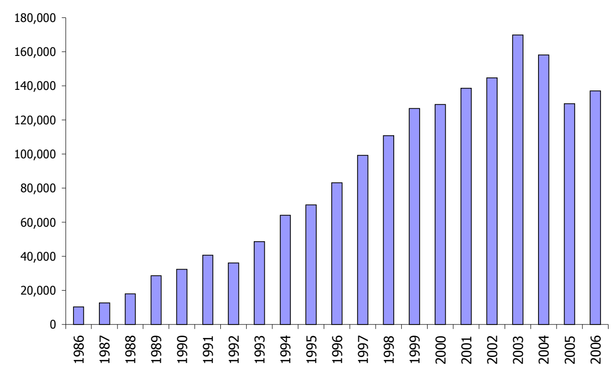

Figure 1. Scottish annual salmon production, in tons (FRS, 2006).

b. Taking a long-term perspective

Successful coastal management must consider the needs of present and future generations. Therefore, administrative structures and policies required to manage the environmental, social, and economic impacts now, must also be adaptable to take account of, and acknowledge, uncertainties in the future.

c. Adaptive management

The coastline has been subject to constant physical and economic changes over the years, and the management of such a dynamic environment requires measures which are able to adapt and evolve accordingly. Successful management should reflect this principle by working towards solutions which can be monitored effectively.

d. Specific solutions and flexible measures

Coastal management measures for each stretch of coast must reflect and accommodate the many variations in the topography, biodiversity, and local decision-making structures. Integrated management should therefore be rooted in a thorough understanding of the specific characteristics of an area, i.e., its local specificity.

e . Working with natural processes

The natural processes of coastal systems are continual, so it becomes necessary in some instances to adopt a different approach that works with natural processes rather than against them. By recognising the physical impacts and the limits imposed by natural processes, decisions regarding the human impact on the coastal zone are made in a more responsible manner and are more likely to respond to environmental change.

f. Participatory planning

In the past, stakeholders may not have had sufficient opportunity to contribute towards the development and implementation of coastal management measures or programmes. Participatory planning incorporates the views of all of the relevant stakeholders (including maritime interests, recreational users, and fishing communities) into the planning process. It can also help to promote a real sense of shared responsibility and coastal stewardship by reducing conflict as real issues, information, and activities which affect the coast can be aired more openly.

g. Support and involvement of all relevant administrative bodies

Administrative policies, programmes and plans (land use, spatial, energy, tourism and regional development, for example) set the context for the management of coastal areas and their natural and historical resources. Addressing the problems faced by coastal zones will therefore require the support and involvement of all relevant administrative bodies at all levels of government to ensure cooperation, coordination and that commons goals are achieved. It is therefore essential to engage key bodies from the start so that decisions are consistent and firmly based on local circumstances.

h. Use of a combination of instruments

Managing the different activities which take place on the coast requires the use of a number of different policies, laws, and voluntary agreements. While each of these approaches is important, achieving the right combination is key to resolving conflicts, as these instruments should work together to achieve coherent objectives for the planning and sustainable management of coastal areas.

The second objective, the protection of ecosystem structure, may be intimately linked to the third, protecting ecosystem function, especially where the structure of habitats have dominant functional roles. For example, mangroves have been shown to have key functional roles in flood protection, nutrient recycling and as nursery areas (Holmer, 2003; Primavera, 1998; Primavera, 2005). However, habitats may be deemed worthy of protection when their precise contribution to ecosystem function is unknown but they are considered to be rare or have rare species assemblages, e.g., cold water corals and moves to protect them from trawling damage (Roberts et al., 2006).

Interactions between aquaculture and sensitive habitats or species can be minimized by establishing aquaculture zones in areas with less sensitive/important/rare habitats, or by designations that more closely regulate developments with respect to their interactions with particular features of concern. In Europe, Special Areas of Conservation (SACs) have been established under the Habitats Directive (92/43/EEC) for the protection of specific habitats.

As this is an important piece of legislation, with wide ranging impact, it is worth exploring this further. The UK Joint Nature Conservation Council gives the following background on its website (www.jncc.gov.uk).

"In 1992 the European Community adopted Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora (EC Habitats Directive). This is the means by which the Community meets its obligations as a signatory of the Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention). The provisions of the Directive require Member States to introduce a range of measures including the protection of species listed in the Annexes; to undertake surveillance of habitats and species and produce a report every six years on the implementation of the Directive. The 189 habitats listed in Annex I of the Directive and the 788 species listed in Annex II, are to be protected by means of a network of sites. Each Member State is required to prepare and propose a national list of sites for evaluation in order to form a European network of Sites of Community Importance (SCIs). Once adopted, these are designated by Member States as Special Areas of Conservation (SACs), and along with Special Protection Areas (SPAs) classified under the EC Birds Directive, form a network of protected areas known as Natura 2000. The Directive was amended in 1997 by a technical adaptation Directive. The annexes were further amended by the Environment Chapter of the Treaty of Accession 2003.

The Habitats Directive introduces for the first time for protected areas, the precautionary principle; that is that projects can only be permitted having ascertained no adverse effect on the integrity of the site. Projects may still be permitted if there are no alternatives, and there are imperative reasons of overriding public interest. In such cases compensation measures will be necessary to ensure the overall integrity of network of sites."

In Loch Creran on the west of Scotland, for example, an SAC has been implemented to protect the unique reefs of the tube building polychaete *Serpula vermicularis* and reef forming horse mussels *Modiolus modiolus*. Several management principles are invoked in marine SACs (www.argyllmarinesac.org):

- Management should enable the natural habitat types and the species habitats concerned to be maintained or, where appropriate, restored at a favorable conservation status.
- Steps must be taken to avoid deterioration or disturbance of the habitats and species for which the site has been designated.
- Activities, plans or projects likely to have a significant effect upon the features of the site must be subject to an appropriate assessment. A development that would have an adverse effect on the conservation interests of the site should only be permitted

if there is no alternative solution and there are imperative reasons of overriding public interest, including those of a social or economic nature.

- Monitoring must be undertaken at each site to monitor the condition of the conservation features and to assess the effectiveness of management measures.
- Management of the site must take into account the economic, social, cultural and recreational needs of the local people.

Loch Creran was one of the original sites in Scotland developed for fish farming with continuing major aquaculture activity both from shellfish and salmon farming. However, any proposed change to the aquaculture activity must be assessed against these principles. In practice, the operator has found it possible to continue to farm in Loch Creran, despite the SAC, by being able to show that any proposed changes will have little impact on the conservation feature.

In general, the science of interactions between sensitive habitats and aquaculture is not well developed, and it is only where catastrophic impacts occur on relatively visible habitats, such as mangroves or seagrasses (Holmer et al., 2003; Orth et al., 2006), that research effort is focused. Thus for many habitats, neither the precise functional significance nor the sensitivity to aquaculture is known with any certainty and regulation is more problematic.

In addition to loss of habitats, reduction in genetic diversity can also be regarded as having a structural component that may or may not also have a functional aspect. For example, the release of genes, disease organisms and parasites for salmon culture and their effects on wild populations have received considerable attention. Wild Atlantic salmon maintain their high degree of population structure by homing to natal rivers for breeding. The resulting genetic diversity has been shown to be important in terms of fitness and can be severely eroded by interbreeding with escaped cultured salmon or from intentional translocations of fish with maladapted genes (McGinnity et al., 2003). Modeling work has shown that, under high rates of intrusion of cultured fish, significant changes to populations will occur that may not recover even if the intrusion rate is reduced (Hindar et al., 2006). For marine species, such as Atlantic cod and European sea bass, the consequences of genetic interactions on populations are not well established.

The potential interactions between parasitic sea lice on wild and cultured populations have also received considerable attention and publicity. Salmon host ectoparasitic parasitic sea lice *Lepeophtheirus salmonis* and *Caligis elongatus* which feed on the skin and underlying tissue. In salmon culture these can increase rapidly to high abundance if left untreated nd infestations can result in severe legions and mortality. Sea lice larvae are adept at find hosts and increasing infestations on juvenile Atlantic salmon and sea trout *Salmo trutta* were blamed on infection pressure from salmon farms. This in turn was linked to reduced survival and population declines of these salmonids. While causal links are extremely difficult to prove (McVicar, 1997), there seems little doubt that sea lice from farmed salmon can (Murray & Gillibrand, 2006) and do (Bjorn et al., 2001) infect wild salmonids cause mortality, particularly to sea trout.

Different approaches have been taken to regulate escapes and parasites in different countries. In Scotland, the government now require statutory declaration of escapes including the approximate number and size of fish, the location and date of escape (Scottish Statutory Instrument 2002 No. 193, The Registration of Fish Farming and Shellfish Farming Businesses Amendment (Scotland) Order 2002). In the planning process, developments of farms near important salmon rivers is discouraged, and farmers are obliged to show how they have taken steps to minimize escapes and improve containment. In Scotland, there is no statutory limit at present for the average lice infestation of salmon that is permitted before treatment with antiparasitic medicines, although there are several voluntary agreements in place between the fish farming sector and the fisheries sector (Area Management Agreements). This is in contrast to Norway, where when statutory lice limits are exceeded, treatment is compulsory (Heuch & Mo, 2001). The situation is likely to change in Scotland as new legislation, aimed at ensuring farmers keep lice levels low, is enacted (Aquaculture and Freshwater Fisheries Bill). This will require fish farmers to record levels of parasites and to ensure that burdens are kept low, but the precise mechanism for achieving this has yet to be announced.

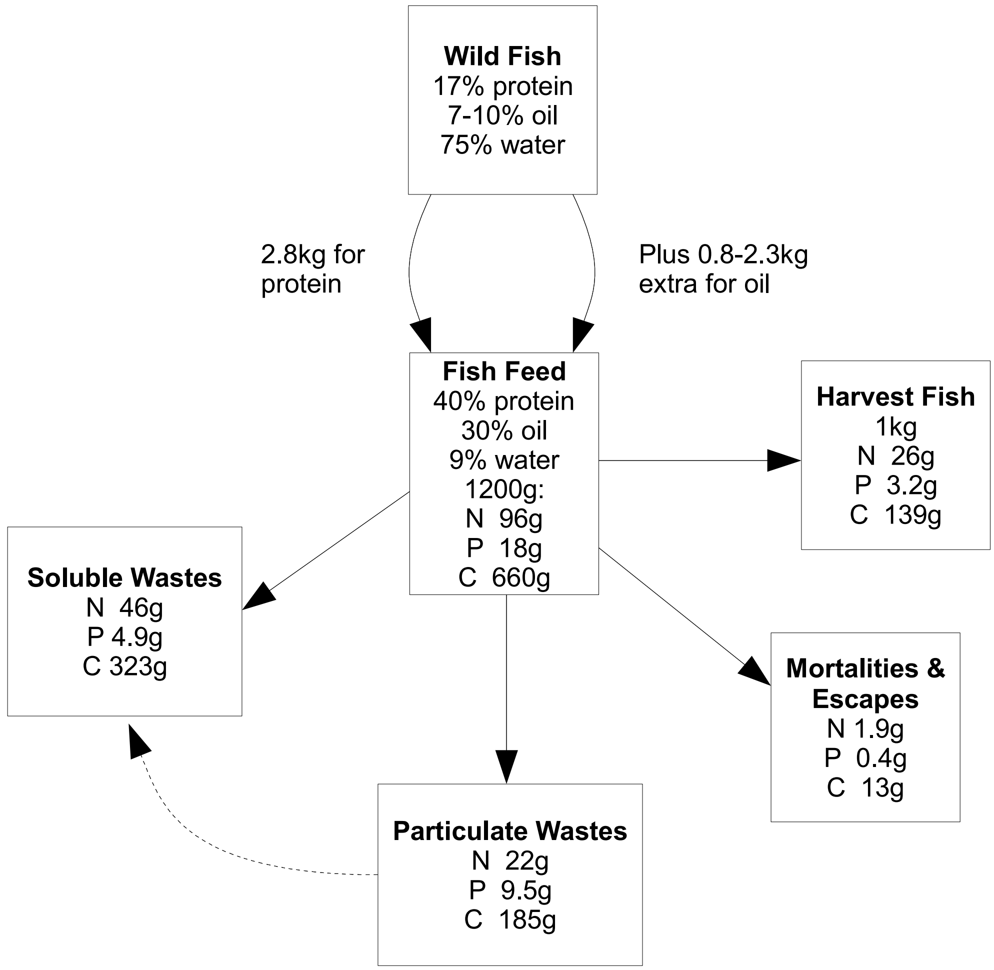

Figure 2. A budget for the flow of nutrients from oceanic wild caught fish to the coastal environment for a harvest of 1kg of farmed salmon assuming no substitution with vegetable protein or oil and a ratio of fish feed o product of 1.2:1 (Black, 2001).

The state of knowledge of the structural effects of fish farming and their sound regulation is rather weak. In contrast, the third objective of regulation, to protect ecosystem function from the consequences of aquaculture, is often better understood and quantified. We now briefly review the current state of knowledge for the main environmental outputs from aquaculture, focusing on marine fish farming, and for each of these we comment on issues related to regulation.

In general, the environmental interactions posed by intensive marine shellfish culture are fewer than for fin fish culture owing to the fact that shellfish are net extractive of nutrients. However, they do concentrate organic material and deposit wastes as faeces and pseudofaeces, causing enrichment of the local benthos (Chamberlain et al., 2001) and, if cultured in sufficiently high density in some areas, can clear the water to such an extent that they reduce productivity (Smaal et al., 2001). Regulation on shellfish farming is, however, less well developed than for marine finfish farming, owing to its lower perceived environmental risk.

Wastes from fish farming are usually considered in 3 overlapping categories:

1. Soluble wastes, being the products of fish excretion and including reactive nitrogen species such as ammonia;
2. Solid wastes, being mainly uneaten feed material and faeces; and
3. Chemical wastes, being medicines - such as antibiotics and antiparasitics, disinfectants, and antifoulants - such as tin or copper compounds formulated into coatings or paints.

Soluble wastes

Soluble nutrients from aquaculture may constitute a risk of eutrophication. The EU definition of eutrophication is:

"the enrichment of water by nutrients especially compounds of nitrogen and phosphorus, causing an accelerated growth of algae and higher forms of plant life to produce an undesirable disturbance to the balance of organisms and the quality of the water concerned".

The undesirable consequences of eutrophication include (Black et al., 2002):

- increased abundance of micro-algae, perhaps sufficient to discolor the sea and be recognized as a bloom or "Red Tide";
- foaming of seawater;
- killing of free-living or farmed fish, or sea-bed animals
- poisoning of shellfish;
- changes in marine food chains; and
- removal of oxygen from deep water and sediments as a consequence of the sinking and decay of blooming algae.

A nutrient budget for Atlantic salmon shows that the majority of the nutrients that are input to the system are subsequently lost either directly as soluble wastes or through losses from solid particulate wastes (Fig. 2). One method of determining the risk of elevated nutrient concentrations is called the Equilibrium Concentration Enhancement (ECE) model. The ECE model is a box model of dissolved ammoniacal nitrogen arising from farmed fish occurring within an enclosed body of water of known dimensions that is being exchanged at a steady rate (Gillibrand & Turrell, 1997). Model input data include the flushing time and volume of the system, rate of excretion of ammonia by fish, and annual production. Using this model, systems can be ranked in terms of the potential contribution of aquaculture to raise nutrient levels and assigned a Nutrient Enhancement Index (NUI). In Scotland, this index was proposed in a government document called the Locational Guidelines for Fish Farming (Gillibrand et al., 2002). Table 1 shows the predicted ECE for Scottish sea loch systems, their NUI and the distribution of lochs by NUI.

ECE(μmol/L)	No. of Scottish sea lochs	Nutrient Enhancement Index
>10.0	5 (4.5%)	5
3.0-10.0	15 (13.5%)	4
1.0-3.0	23 (20.7%)	3
0.3-1.0	22 (19.8%)	2
<0.3	46 (41.4%)	1
	Total 111	

Table 1. ECE values for nitrogen for Scottish sea lochs and classification using the Nutrient Enhancement Index (Gillibrand et al., 2002). For an ECE of 0 (i.e. where no emission from aquaculture exist) a value of 0 is assigned.

More complex models exist, where the biological response from nutrient additions is predicted in terms of phytoplankton biomass or chlorophyll. One such model, currently being adapted for an aquaculture (Laurent et al., 2006) was initially developed for predictions of the eutrophication potential of nutrient discharges from sewerage marine outfalls. This model, originally called the CSST model, has been described by Tett et al. (2003). Such models are capable of being applied at a range of scales and in non-enclosed water bodies, provided appropriate boundary conditions are known, can be measured, or can be predicted from larger scale models. Absolute standards for what constitutes eutrophication are not available. What constitutes a harmful disturbance to the ecosystem will vary according to the normal seasonal cycle which may be very different in temperate, sub-tropical and tropical regions. Thus to assess the acceptable level of phytoplankton biomass will require some knowledge of annual nutrient cycles and the primary production response for different environments and such measurements have often not been made. An alternative is to look for a deleterious ecosystem response such as the hypoxia caused by enhanced carbon inputs to deeper waters and sediments. Hypoxia may constitute a threat not only to the ecosystem but to the farmed fish themselves.

Solid wastes

The major solid wastes from fish farming are from uneaten feed and faecal material. The quantity of both these components will vary by species, food conversion ratio, food digestibility, and the skill of the operator in matching feed availability to demand.

Benthic macrofaunal communities in sediments receiving normal detrital inputs derived from planktonic production in the overlying water column are species rich, have a relatively low total abundance/species richness ratio, and include a wide range of higher taxa, body sizes, and functional types, i.e. they are highly diverse communities (Pearson, 1992). The total productivity of the system is dependent on the availability of food - organic matter, and its quality. Animals have evolved to maximize the utilization of the available resource by virtue of a wide range of feeding modes and some species can vary their mode of feeding depending on environmental factors. Benthic types include filter feeders that gather detrital material from the water column above the sediment, surface deposit feeders that feed on material deposited on the sediment surface, sub-surface deposit feeders that consume buried organic material by burrowing, and carnivores that prey on other macrofauna. Microbes degrade organic material and are themselves consumed by macrofauna, mediating the transfer of nutrients up the food chain.

A variety of terminal electron acceptors are used by different bacterial communities in marine sediments. The oxygen concentration at any point in the sediment is dependent on the rate of its uptake, either to fuel aerobic metabolism, or to re-oxidize reduced products released from deeper in the sediment. When the oxygen demand caused by input of organic matter exceeds the oxygen diffusion rate from overlying waters, sediments become anoxic and anaerobic processes dominate. As sediments become more reducing with increasing distance from the water column interface, a range of microbiological processes become successively dominant in the order:

- aerobic respiration, ammonium oxidation (to nitrite) and nitrite oxidation (to nitrate). These aerobic nitrifying processes are inhibited by sulphide and are, therefore, of limited importance in sediments beneath marine fish farms;
- denitrification (producing dinitrogen from nitrate);
- nitrate reduction (producing ammonium from nitrate) and manganese reduction;
- iron reduction;
- sulphate reduction (producing hydrogen sulphide);
- and lastly, under the most reducing conditions, methanogenesis (producing methane).

To some extent, these processes may overlap spatially. Oxygen in sediment porewaters is rapidly depleted and sulphides are generated by sulphate reduction, which is the dominant anaerobic process in coastal sediments (Holmer & Kristensen, 1992).

These effects on sediment biogeochemical processes have profound consequences for the seafloor fauna that becomes dominated by a few small, opportunistic species, often at very high abundances, and confined to the upper few centimetres of the sediment (Brooks & Mahnken, 2003a; Brooks et al., 2003a; Brooks et al., 2003b; Hargrave et al., 1997; Heilskov & Holmer, 2001; Holmer et al., 2005; Karakassis et al., 1999; Pearson & Black, 2001; Pearson & Rosenberg, 1978; Weston, 1990). Away from the farm, as organic material flux and oxygen demand decreases, animal communities return to background conditions typified by high species diversity and functionality (Gowen & Bradbury, 1987; Nickell et al., 2003; Pereira et al., 2004).

The redox potential (Eh) profile measured the sediment column to a depth of 10-15 cm gives a useful guide to the relative degree of carbon enrichment in the sediments (Pearson & Stanley, 1979). Positive Eh values are indicative of aerobic conditions whereas negative values are associated with anaerobic microbial processes. Under normal rates of detrital carbon input to sediments, the redox discontinuity level (RDL), i.e., the point at which anaerobic processes become predominant, lies some centimetres below the surface. As carbon inputs increase, the RDL approaches ever closer to the surface as the BOD (Biological Oxygen Demand) within the sediments increases. Eventually, under very high detrital inputs, the RDL coincides with the sediment/water interface, where, under low flow conditions, it might even rise into the water column.

It is important to emphasize that highly organically enriched sediments can occur naturally from large marine or terrestrial inputs of detritus. This may be transient and localized or long-lived and wide scale. Hypoxia/anoxia in sediments and overlying water occurs when the supply of new oxygenated water is poor as may be the case, for example, in deep silted fjordic systems. In such systems, benthic communities are modified and specialist opportunist animals may dominate.

The process of organic particulate material impacting the seabed and causing benthic effects is amenable to modeling (Cromey & Black, 2005; Cromey et al., 2002a; Cromey et al., 2002b; Silvert & Cromey, 2001; Silvert & Sowles, 1996). A widely used model is that of Cromey et al. (2002a) - DEPOMOD. The outputs of this model are in terms of accumulated carbon per unit area of sea bed per unit time - the word accumulation is used here as resuspension processes are accommodated in the model. The output is visualized as a contour plot of carbon deposition on a spatial grid (an example is shown in Fig. 3).

In Scotland, as in several other countries, the regulator (Scottish Environment Protection Agency, SEPA) is required to manage the impacts of fish farming to avoid unacceptable damage of the sea bed and its fauna. SEPA have gone a little further than most regulators in giving some examples of where they think the boundary between acceptable and unacceptable seabed conditions lies. They have established Sediment Quality Criteria (SQC, Table 2) as indicators of when they will take action in order to reduce impacts, e.g., by reducing the maximum allowable biomass or by entirely revoking the discharge consent. The SQC are not the only criteria used - SEPA will accept and consider all the available evidence - but as many benthic indicators co-vary, they do offer a meaningful insight into what SEPA considers to be unacceptable benthic conditions. Discharge consents have monitoring conditions specified in detail: both their level (i.e., the number of stations, types of measurement and analysis) and their frequency are matched to the perceived risk of the farm. For example, a small farm over hard sediment with strong currents will be monitored less intensively than a large farm over a soft substrate with weak currents. This process is given in great detail, together with its underlying philosophy and science, in the regularly-updated Fish Farm Manual that can be downloaded from the SEPA website (www.sepa.org.uk).

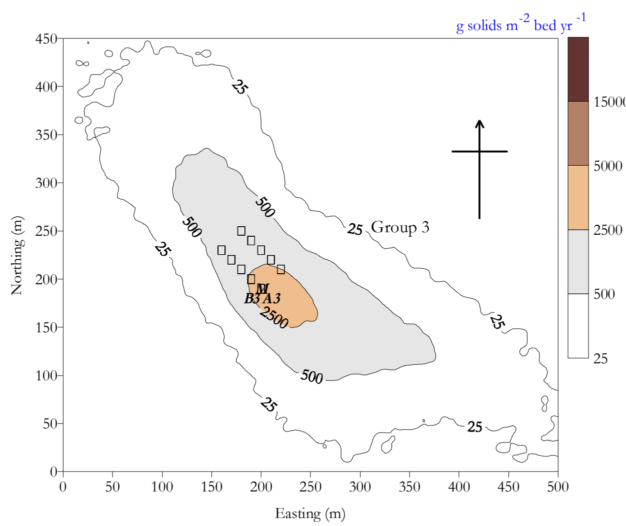

Figure 3. Example of a DEPOMOD particle tracking model output. Cages are represented by squares; the contours show the accumulation of organic matter on the seabed beneath and around the cages.

The SQC (or Action Levels, Table 2) are levels at which SEPA may take action against the farmer, i.e., reduce or remove the consent to discharge. Implicit within the approach are:

(a) that the farmer is required to monitor the sediments around the farm to measure compliance or otherwise, and
(b) the concept of the Allowable Zone of Effects (AZE).

Determinand	Action Level Within Allowable Zone of Effects	Action Level Outside Allowable Zone of Effects
Number of taxa	Less than 2 polychaete taxa present (replicates bulked)	Must be at least 50% of reference station value
Number of taxa	Two or more replicates with no taxa present	
Aundance	Organic enrichment polychaetes present in abnormally low densities	Organic enrichment polychaetes must not exceed 200% of reference station value
Shannon-Weiner Diversity	N/A	Must be at least 60% of reference station value
Inafunal Trophic Index (ITI)	N/A	Must be at least 50% of reference station value
Beggiatoa	N/A	Mats present
Feed pellets	Accumulations of pellets	Pellets present
Teflubenzuron	10.0 mg kg^{-1} (dry wt)/5cm core	2.0 μg kg^{-1} (dry wt)/5cm core
*Copper**	Probable Effects 270 mg kg-1 dry sediment Possible Effects 108 mg kg-1 dry sediment	34 mg kg^{-1} dry sediment
*Zinc**	Probable Effects 410 mg kg-1 dry sediment Possible Effects 270 mg kg-1 dry sediment	150 mg kg^{-1} dry sediment
Fruu sulphide	4800 mg kg^{-1} (dry wt)	3200 mg kg^{-1} (dry wt)
Organic Carbon	9.00%	
Redox potential	Values lower than -150mV (as a depth average profile OR Values lower than -125mV (in surface sediments 0-3 cm)	
Loss on ignition	27.00%	
**A detailed description of the derivation of these action levels may be obtained from SEPA on request*		

Table 2. Sediment Quality Criteria (SEPA Fish Farm Manual, Annex A).

The AZE represents an area around the farm where some deterioration is expected and permitted. Thus for several determinands, two SQCs are proposed: one within the AZE and one at any point outside the AZE. The SQC inside the AZE is less demanding than that outside the AZE. The SQC approach thus constrains the level of ecological change while the AZE limits the spatial extent of major changes.

Chemical wastes

Several classes of chemicals are used in fish farming. Three of the most important are antibiotics, antiparasitics and antifoulants. Since the advent of effective fish vaccines for several important bacterial diseases, the use of antibiotics in salmon culture has declined since the early 1990s (Alderman, 2002), but less is known about the use of antibiotics in other species, particularly those in the developing world (Gräslund & Bengtsson, 2001; Holmström et al., 2003; Tacon et al., 1995). The main concerns relating to antibiotic use relate to the possibility of the development of bacterial resistance that can be transferred to human pathogens reducing the efficacy of antibiotics in human medicine (Cabello, 2004; 2006). Prophylactic use of antibiotics is a particular concern, as is adequate testing of aquaculture products for antibacterial residues. Where residues persist, low levels of antibiotic intake can stimulate resistance in human pathogens but another concern is that some of the antibiotics used in aquaculture may not be approved for human medicine and carry a health risk. For example, nitrofurans (e.g., furazolidone) are a group of antimicrobials which possess either carcinogenic or mutagenic properties whose use is banned in many countries but still permitted in some. In general, limits have not been set for the concentrations of antibiotics permitted in the environment.

Of the antiparasitics, the best studied are those that treat infestations of sea lice on salmonids. These are generally highly toxic substances where the use is tightly regulated. In Scotland, for example, ecological quality criteria have been set both for both sediments and the water column (www.sepa.org.uk) and access to these medicines is strictly controlled. Medicines are only available to farmers after a multi-step regulatory process of authorization that includes testing for efficacy, food safety, and environmental effects.

The most infamous antifoulant product, now banned, is tributyltin (TBT). TBT disrupts the endocrine system in invertebrates leading to imposex (Miller et al., 1999) and has now been replaced by products with a high concentration of copper. Copper, however, is also a potent toxin, hence it's utility as an antifoulant, and quality criteria have been set for both the water column and sediments. A recent study at a fish farm in Scotland found copper at higher concentrations than the sediment quality criteria (Dean et al., 2007) although its toxicity in anoxic sediments may be limited by its precipitation as the sulphide (Brooks & Mahnken, 2003b).

CONCLUSIONS

The regulation of aquaculture in developed countries has developed considerably over the past decade. This has been driven by the need to improve the scientific basis for management of this very high economic value sector. Regulators must base their decisions of good science in order to protect the environment but at the same time allowing development with its economic benefits. This has particularly been the case for the major salmon growing countries, although Chile perhaps has still to catch up in a regulatory sense with its rapidly expanding industry. In the developing world, where aquaculture products are primarily for export, market pressures are increasingly brought to bear to ensure food safety, for example concerning residues, and there is also a growing awareness of environmental issues, particularly relating to habitat destruction related to shrimp farming. In the Philippines, regulation of the very large number of small scale fish farms where the market is local represents a significant regulatory challenge, but the potential environmental costs make rational regulation essential for the future of this industry. In this paper we have outlined some of the approaches being taken by aquaculture regulators in other countries. It is highly likely that some of these approaches will be relevant and adaptable to the Philippine industry.

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