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SUMMARY – Aquaculture interacts with wildlife through its consumption of resources, through the aquaculture process itself and through the release of wastes into the environment, especially feral fish. Land or space is required in which to establish the farm and feed required to promote growth and production. Farms are often established in remote locations and young fish or fry translocated for stocking purposes. Both cage and raft structures themselves and the high densities of fish and feed at fish farms may act as attractants to scavenging and predatory species while routine farm activities can disturb sensitive species. In addition to damage to stocks and equipment, predators and scavengers can spread disease or sufficiently stress farmed stock to adversely affect production. There is evidence indicating that a great many birds and mammals are killed on farms, either deliberately or by accident. Methods for deterrence are discussed. Farmed aquatic animals inevitably escape or, in the case of molluscs, extend their range and often become established. The fear is that they will either cause damage to habitats or compete with, or predate on, indigenous flora and fauna. There is little supporting evidence from marine environments, however, and many of the conclusions with regard to impacts on finfish stocks have been drawn from the atypical example of Atlantic salmon.

Key words: Aquaculture, wildlife, birds, cages.

RESUME – *"Interactions de l'aquaculture et la faune et flore". L'aquaculture interagit avec la faune et la flore à travers sa consommation de ressources, à travers le processus d'aquaculture lui-même et à travers la libération de résidus dans l'environnement, spécialement, les poissons sauvages. Il faut des terrains ou de l'espace pour établir les fermes et les aliments sont nécessaires pour promouvoir la croissance et la production. Les fermes sont souvent établies dans des zones éloignées et les jeunes poissons ou alevins sont transférés pour l'élevage. Les structures de cages et radeaux et les fortes densistés de poissons et d'aliment dans les centres de pisciculture peuvent attirer des espèces prédatrices et charognardes, tandis que les activités de routine de la ferme peuvent déranger des espèces sensibles. En plus de nuire aux stocks et à l'équipement, les prédateurs et charognards peuvent propager des maladies ou stresser les animaux d'élevage au point d'affecter négativement la production. Il y a de bonnes raisons qui indiquent qu'un grand nombre d'oiseaux et de mammifères sont tués dans les fermes, soit délibérément, soit accidentellement. On examine des méthodes de dissuasion. Les animaux aquatiques d'élevage s'échappent inévitablement ou, dans le cas des mollusques, ils élargissent leur étendue et souvent ils se sont installent. Le problème est qu'ils peuvent causer des dégâts aux habitats ou bien ils peuvent rivaliser, ou attaquer la flore et la faune indigènes. Cependant, il y a peu de preuves de ceci provenant d'un environnement marin, et beaucoup de conclusions concernant les impacts sur les stocks de poissons ont été tirées de l'exemple atypique du saumon atlantique.*

Mots-clés : *Aquaculture, faune et flore, oiseaux, cages.*

Introduction

Aquaculture interacts with wildlife in a number of ways, some of which are perhaps less immediately obvious than others (see Fig. 1). Farms are often built in remote rural areas, utilising land or an area of the seabed that had previously been undeveloped. Exotic species or strains of animal are imported for stocking and the stock must be fed and looked after until harvest. Demands for feed ingredients, especially fish meal and fish oil products, can exacerbate pressures on already over-exploited natural resources. Increases in road and boat traffic and noise may drive away resident species sensitive to disturbance. In contrast, the large concentrations of fish and food may attract predators and scavengers, creating direct economic costs to farmers through damage to nets, loss of stock and feed as well as posing a risk in terms of spread of disease. The predators attracted to an area by fish and shellfish farms can further

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adversely impinge on wildlife through increased predation or increased competition for breeding sites. Wastes – uneaten food, faecal and excretory products – are inevitably released into the environment, impacting on the seabed under and immediately surrounding the farm. Feral (escaped) farmed fish pose a potential risk to resident flora and fauna through habitat destruction, interspecific (predation) and intraspecific (competition) interactions.

The present paper reviews aquaculture – wildlife interactions, with particular emphasis on cage culture of fish in coastal environments and the Mediterranean region, and considers remediation options.

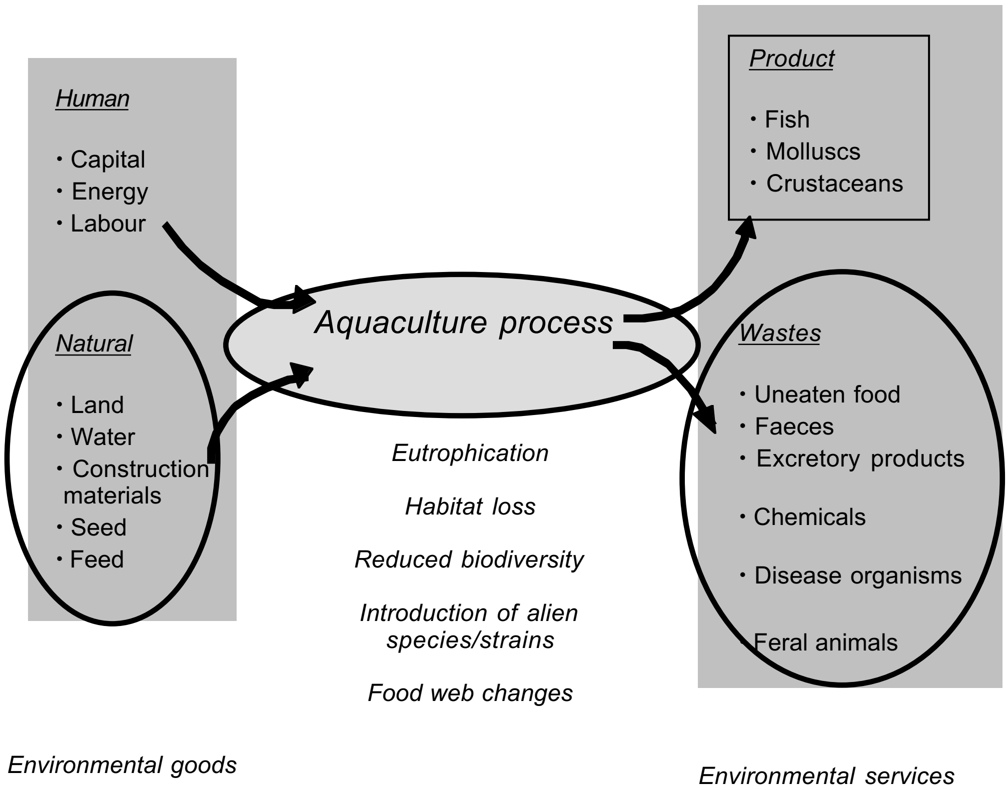

Fig. 1. Diagram, illustrating the relationship between resource use, the aquaculture process and waste production and the impact of consumption of environmental "goods" and "services" on eutrophication, food web changes, habitat loss and biodiversity.

Natural resource consumption and wildlife

Change in habitat use

Fish farms require land or, if cage-based, occupy areas of the seabed. Most Mediterranean fish and shellfish farms utilise water-based production systems – i.e. cages and rafts and long-lines – and provided they are sited sensitively, offer little threat in terms of loss of important wildlife habitat. However, a small number of inappropriate developments have adversely impacted on wildlife and the intensification of production methods in some traditionally farmed areas is giving cause for concern. Some 300 mussel farms have been established in the Bay of Thessaloniki, Greece, within a few hundred metres of an important Ramsar site (A. Kamarianos, from a presentation at the Seminar). Increased boat and human activity associated with the development is one of the contributing factors behind disturbance of birds. Mediterranean coastal salt ponds ("salinas") in France, Spain and Portugal are used by both resident and over-wintering wading birds, such as the black-winged stilt (*Himantopus himantopus*), for foraging (Rufino *et al.*, 1984; Britton and Johnson, 1987). A number of salinas have been converted into fish ponds, resulting in declines in bird numbers. Loss of feeding habitat and increased levels of disturbance have been implicated (Rufino and Neves, 1992).

In Italy and Greece, some 40,000 ha of lagoon systems are still managed for the extensive culture of sea bass, bream, mullets and eel (e.g. "vallicoltura"), albeit that there has been a certain amount of intensification of production methods in recent years. Such systems have been in existence for centuries with no reported adverse affects on wildlife. Indeed, they provide valuable feeding roosting and breeding grounds for many species (Dell'Agnello, 1999). However, in certain areas, such as in the coastal wetlands of western Greece, it is feared that further elaboration and intensification of traditionally managed coastal bass and bream ponds adjacent to Ramsar sites may adversely affect the sites' conservation value.

Wild seed

Marine fish tend to produce smaller eggs, have more complex early life stages and produce fry whose quantitative and qualitative nutritional requirements appear to be much more complex than those of freshwater fish. As a result, the farming of marine fish is more dependent on wild stock and contrasts sharply with freshwater fish farming. Most freshwater species are reared throughout their life cycle in captivity, a desirable state of affairs from the farmer's point of view since it facilitates selection for economically important traits and is a pre-requisite in the manipulation of sex and in the development of year-round supplies of seed (Beveridge *et al.,* 1997a). Although some sea bass and sea bream fry are still caught in lagoons for sale to farms for grow-out, these days most finfish seed stocked on commercial farms in the Mediterranean is of hatchery origin. Farming of yellowtail (*Seriola dumerili*) in Italy, Spain and Croatia remains dependent upon fattening of wild-caught juveniles (García-Gómez and Ortega-Ros, 1993), and although nothing is known about impacts of seed collection on wild stocks, it is probably negligible given the present size of the industry. The northern bluefin, or red, tuna (*Thunnus thynnus*) has been "farmed" on a commercial basis in Morocco, Spain and Croatia and elsewhere since 1995. The activity depends upon fattening of wild caught fish for six months or so and it remains to be seen whether captive rearing for such short periods of time will continue to be regarded as aquaculture for trade purposes (Belmonte *et al.*, this volume). High profit margins are likely to ensure that tuna farming will continue to expand, although it is unclear whether this adds much additional pressure to wild stocks.

There has been little study of the impacts of collection of mollusc spat on wild stocks. Studies of mussel spat collection conducted some time ago in the Wadden Sea showed evidence of declines in wild stocks, with consequent adverse effects on eider ducks (*Somateria mollissima*) (Dankers and Zuidema, 1995).

Feed consumption

Intensive fish culture is heavily dependent upon fish meal and fish oil supplies. At present, it is estimated that aquaculture accounts for up to 23% of fishmeal use and 28% of fish oil use. Fourtonnes of fresh fish is required to produce one tonne of fish meal. A typical marine fish diet contains something like 35% fishmeal and 20% fish oil. Assuming average FCR values of 1.8:1 for seabass and 2.0:1 for sea bream, the Mediterranean marine finfish industry currently uses something like 55,000 t fishmeal, equivalent to less than 0.1% of fishmeal utilised by the aquaculture sector. The demands of the aquaculture sector are likely to increase as production expands and, in China and elsewhere in Asia, production methods intensify (Tacon, 1999). Supplies are finite, demand is increasing and several of the stocks that form the basis of the fishmeal and fish oil industries are already exploited at unsustainable levels.

While scientists are actively seeking alternatives to fish-based dietary constituents, there are a number of both dietary and economic constraints to consider. Oilseed meals represent one of a number of contenders to replace fishmeal (Alexis, 1997), although depending upon source and inclusion rate, they may compromise palatability, growth (Stickney *et al*., 1996) and, possibly, profitability. Moreover, any decrease in palatability or diet digestibility may aggravate waste loadings to the environment. The issue of fish oils is perhaps even more pressing than that of fishmeal. Aquatic carnivores are poor at using carbohydrate to supply energy requirements, relying instead on protein and lipid (Cowey and Sargent, 1977). The substitution of fish oils with vegetable oils in freshwater carnivorous/omnivorous fish diets is possible (Buzzi *et al*., 1997).

However, there are limitations when it comes to marine carnivores such as seabass, as they require n-3 highly unsaturated fatty acids (HUFAs) which at present can only be derived in commercial quantities from fish oils (Bell *et al*., 1986). Pressures on fish oil supplies are even greater than those on fish meal.

The aquaculture process

Aquaculture usually involves establishing farms in areas away from human centres of population. Importation of seed or young fish may be necessary for stocking. The cage and raft structures act as fish attractant devices (FADs), offering shelter to some species and a habitat for predators. The large quantities of feed attract scavengers that can damage unprotected bags of food, spoiling and spilling food in the process, and consume uneaten food as it falls through the cages. Predators are attracted by the presence of such large numbers of fish and shellfish. Predators and scavengers can become established and displace less aggressive native species. For example, breeding populations of gulls, attracted by food availability at cage salmon farms, have displaced terns colonies in some sea lochs in Scotland (Furness, 1996). Day-to-day farming operations inevitably increase the presence of humans and involve greater vehicular and boat traffic, thereby aggravating levels of disturbance.

Predators

Diving ducks can dive to depths of up to 30 m. They feed on marine invertebrates, including mussels, and can consume up to 5 kg/day (Furness, 1996). From the predator's point of view farmed mussels are superior to wild: they are rich in lipids, thin-shelled and give high rate of energy return per unit foraging time. Eider duck numbers are increasing in areas associated with mariculture in northern Europe and have also been known to alter their seasonal pattern of movements to take advantage of farm practices (Furness, 1996). Eider ducks cause an estimated ~ Euros 6000 damage per mussel farm per year.

There is an enormous range of predatory species, including squid, fish, turtles, reptiles, birds, mammals, although birds are the principal problem at Mediterranean farms. Predators can kill or wound fish, damage equipment, resulting in losses through escapes, stress fish that results in reductions in appetite that in turn causes poor growth and reduced resistance to disease. This in turn causes poor production and profitability.

Most studies of bird predation at fish farms have been carried out in northern Europe. In Scotland, for example, an estimated 60-90% fish farms have bird-related problems; cormorants (*Phalacrocorax carbo*), herons (*Ardea cinerea*) and shags (*P. aristotelis*) are by the far the largest cause of problems; gulls (*Larus* spp.) less so. An estimated 80% fish farms have also been attacked by seals. Melotti *et al.* (1994) studied predation of sea bass in Adriatic fish ponds by piscivorous birds and found that the incidence of predation was independent of stocking density, but dependent upon size (age) of fish, predation on yearlings being higher than on second year fish. A few studies have also been carried out in freshwater fishponds in France and Israel (Genard *et al.,* 1993; Be'er, 1995; Shy and Frankenberg, 1995). In Israel, concerted efforts have been made to deter cormorants from visiting ponds, principally through use of scaring tactics such as scare cannons, sirens and shooting (Shy and Frankenberg, 1995). However, while causing an effective decline in numbers, the harassment techniques have impaired breeding of the protected pygmy cormorant *P. pygmaeus* (Be'er, 1995).

Several methods of deterrence and exclusion have been proposed. At its simplest level, the presence of dogs or scarecrows can deter predators and scavengers. More sophisticated approaches include the installation of scaring devices that utilise flashing lights or sounds such as recorded boat engines or loud bangs. Although such devices can be effective, experiences differ, some farmers claiming that predators and scavengers soon become habituated. Simulation may need to be reinforced by real events, such as the appearance of the farmer or the arrival of a boat. Others claim that scaring devices may simply displace predators to nearby farms. Exclusion devices – 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. Exclusion systems for ponds and shellfish farms can be prohibitively expensive. The best strategy for ponds is to focus on protecting the most vulnerable stock sizes, often the fry-fingerling stages that may be held in smaller, easier to protect ponds. Various systems of anti-bird wires or exclusion cages are used (see Welcomme, 1988a, for details). Melotti *et al.* (1994, 1996) have demonstrated that netting significantly reduced mortalities and the incidence of wounding in pond-reared sea bass and sea bream. Mussel long-lines are much more difficult to protect than raft systems (Furness, 1996).

Although increasing tubidity has been shown to decrease effectiveness of predation by little egrets (*Egretta garzetta*) in fish ponds (Cezilly, 1992), few farmers would countenance this in view of increased risks of gill damage and decreased food conversion ratios.

Many studies have shown that killing predators is ineffective (Beveridge, 1988). The shooting of cormorants, for example, primarily kills migratory birds that are rapidly replaced by newly arriving individuals (Keller *et al.*, 1998). Moreover, it is usually illegal.

Farmed organisms and disease

Movements of fish and other aquatic organisms for aquaculture purposes have been responsible for the spread of a number of diseases, including the well-documented introduction of the monogean *Gyrodactylus solaris* to Norway that has resulted in a catastrophic decline of wild salmon in many rivers (McVicar, 1997). There is little evidence of problems in the Mediterranean, although there are concerns that viral nervous necrosis (VNN), caused by nodavirus (Le Breton *et al*., 1997), may be spread through unregulated movements of sea bass stocks and that greater enforcement of regulations is necessary.

Relationships between wild and farmed stocks and pathogens are complex and poorly researched. Circumstantial evidence for spread of disease among farmed fish by wildlife is strong. Scavenging and predatory birds and mammals are well known as vectors or hosts of a range of disease agents, including viruses, bacteria, parasites (Beveridge, 1988; McAllister and Owens, 1992; Anon., 1997; Baccarani *et al*., 1998; Blanc, this volume). However, there is no incontrovertible evidence that birds or mammals have been the vector for the spread of a particular pathogen to a fish farm. Moreover, there is evidence that through unregulated movements of farmed fish and shellfish aquaculture has caused the spread pathogens to wild populations (see above). The establishment of a farm can also disrupt the balance between pathogen and host, creating conditions that promote the rapid build up of pathogens among wild and/or farmed stock.

Wastes and wildlife

Introduction

Aquaculture wastes can be considered to include all material released into the environment during the course of production and therefore comprises not only uneaten food, faecal and urinary products, but also drugs and chemicals, microorganisms and feral (escaped) animals (see Fig. 1). With regard to wildlife I focus primarily on feral animals.

Uneaten food, faecal and metabolic wastes

It is well known that uneaten food and faecal material from aquaculture systems impacts on benthic environments. It has been demonstrated in the Mediteranean that if farms are inappropriately sited they can adversely affect seagrass (*Posidonia oceanica, Cymodocea nodosa*) meadows, causing decreases in shoot density and even death, depending upon farm size, waste production and currents (Delgado *et al*., 1997, 1999). Increased nutrient availability promotes growth of epiphytes that in turn is hypothesised to attract grazing fishes, thereby increasing grazing pressure and damage to standing crops. Increases in turbulence and/or settled wastes are also believed to reduce light penetration or smother and kill plants. Even after farms have been removed, the meadows may continue to decline, as in Fornell's Bay Menorca (Delgado *et al*., 1999).

Increased sedimentation of organic matter can also change benthic infaunal community structure and thus food availability for fish and crustaceans (Black, 1998). Such impacts may in turn cause conflict with other sectors of the economy dependent on wildlife (fishing, tourism).

Escaped (feral) animals

Although more than 200 aquatic species are currently farmed, aquaculture remains heavily reliant on a handful of species that have been extensively translocated around the globe in order to capitalise on production know-how and markets (Welcomme, 1988b; Beveridge *et al*., 1997b). It has been widely argued that such organisms inevitably escape, become established and adversely impact on the environment and on biodiversity. The unregulated movement of species for aquaculture purposes also poses serious risk of transmission of pathogens.

In a recent analysis of FishBase[2] records, Bartley and Casal (1998) showed that of some 2600 records of fish introductions, aquaculture development was the single most important reason cited for introductions. Little, however, has been documented about shellfish movements for aquaculture purposes. While few fish have been introduced to the Mediterranean region for aquaculture purposes[3], shellfish introductions include the Manila clam (*Ruditapes philippinarum*) and various crustaceans including the freshwater red swamp crayfish (*Procambrus clarkii*) and the marine shrimp *Penaeus japonicus*.

How many farmed organisms escape? It has long been argued that water-based systems – cages and rafts and long-lines – represent a particular risk in this regard. There is an almost continuous release of fish from cages during day-to-day operations such as stocking, grading and disease treatment, punctuated by occasional mass releases that occur as a result of storms, predator damage and accidents. Anecdotal stories abound in the press: however, there is also evidence from the insurance industry, one such estimate being that 1.5% of fish stocked in cages escape (Beveridge, 1996). Mussel farms must also be regarded as an important source of recruitment to wild mussel populations in some areas, although this is rather poorly studied. All of the shellfish introductions to the Mediterranean may be readily found in the wild.

What are the impacts of feral farmed aquatic organisms? The fear is that feral species become established and adversely impact on indigenous biodiversity. Leaving aside possible biases arising from the fact that assessments are largely based on questionnaires and therefore prone to bias, an estimated 65% of introductions for aquaculture purposes have lead to established populations (Bartley and Casal, 1998). However, fewer exotic fish species appear to become established in the marine environment than in fresh waters (Baltz, 1991). Many farmed aquatic organisms share characteristics in common with species termed *r*-strategists[4] by ecologists and according to ecological theory such feral species should be the most successful colonisers. However, again, analysis of available data suggests little correlation (Bartley and Casal, 1998), although reliance on a single criterion – establishment negatively correlated with maximum body size – by the researchers, the acknowledged paucity of data or the time frame of the studies may not provide a truly definitive answer.

Negative environmental impacts of feral organisms arise either from abiotic (habitat damage) or biotic (increased competition and predation) interactions. The former is regarded as rare, the most

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[2] An extensive database on fish developed by ICLARM and FAO with support from the European Commission.
[3] Notable exceptions include the North American channel catfish to Italy.
[4] i.e. species with high fecundity, rapid early development, rapid growth, wide environmental tolerances and food preferences, etc.

frequently cited example probably being that of grass carp (*Ctenopharyngodon idella*) on vegetation and thus plant biodiversity and wildlife habitat (Beveridge *et al.,* 1994). Grass carp, however, are believed not to breed outside of their native China and have not been reported as causing problems in the Mediterranean area. By contrast, the introduction of red-claw crayfish from the United States to irrigated agriculture areas in the Iberian peninsula has proved disastrous, leading to millions of Euros worth of damage to irrigation structures and lost rice production as well as serious and unexpected impacts on wildlife (Arrignon *et al.*, 1994). Competition and predation are much more serious. Again, it has been widely assumed by Moyle and Light (1996) and others that the introduction of top carnivores would cause more serious negative impacts than that of omnivores or herbivores. However, Bartley and Casal (1998) show that the 81% of introductions of omnivores caused negative ecological impacts compared with around 60% associated with introductions of carnivores and herbivores.

With regard to competition it is not just species but strains that may have to be considered and particular concern has been voiced about the impact of feral Atlantic salmon on wild stocks. In Norway, in 1997, more than 50% of Atlantic salmon caught by fishermen were of farmed origin while in the Faroe islands as many as 60% of recent salmon catches have been established to have escaped from salmon farms (Hansen *et al*., 1999). Genetically distinct, non-interbreeding populations of Atlantic salmon occur in each river system. The fear is that feral farmed salmon will inter-breed with local populations, introducing genes that reduce the fitness of individuals and put the population at risk. A number of studies have shown escaped farmed salmon can cause long-term genetic changes in natural populations that affect both single-locus and highly heritable quantitative traits, such as growth and sea age of maturity (McGinnity *et al.*, 1997). However, while under some circumstances such changes may lead to reduced fitness and productivity, the widely reported declines in wild stocks are almost certainly due to a complex interaction of factors, including over-fishing, habitat modification and climate change. Atlantic salmon must be considered a special case and it is dangerous to extrapolate to other species (Beveridge *et al*., 1994). Although most marine fish produce pelagic eggs, there probably exist genetically distinct populations of most fish species of aquaculture interest in the Mediterranean. Information on stocks, sadly, is limited. However, Mediterranean-wide movements of sea bass and sea bream have – and still, unfortunately, do – occur for aquaculture purposes. Some believe that this trade may well have compromised genetic integrity of stocks, not only impacting on biodiversity but also limiting material that farmers might use in the future as a basis for selection of economically desirable traits.

Discussion

Although there has been little study of the phenomenon, the development of aquaculture in the Mediterranean has undoubtedly created new habitats and new opportunities for wildlife, especially predatory and scavenging bird species such as gulls, herons and cormorants. Only in Israel can it be demonstrated that aquaculture has caused any significant change in bird distribution.

There have been a number of European Commission Directives that if implemented properly should ensure adequate protection for endangered habitats and wildlife species. Perhaps the single most important instrument is the protocols on special protected areas in the Mediterranean, the most recent of which was signed by all but two Mediterranean states in Barcelona in July 1995. Using the Natura 2000 and other relevant guidelines, this was an attempt to establish a consensus on the criteria that should be used to identify areas of conservation value. Many are of relevance to wildlife interests, including not only those representative of various habitat types and habitats under threat, but also those necessary to support essential functions (breeding, feeding, etc.) of the more than 100 species believed to be endangered (see also Alvarez, this publication). Under Directives 79/409, 92/43 and 97/11EU member states can insist that EIAs are carried out for any significant aquaculture development or expansion.

While it is true that aquaculture has been a minor source of exotic species introduction in the marine environment by comparison with ballast water in ships (Gollasch *et al*., 1999), a number of exotic aquatic vertebrates have been introduced as a result of fish farming. In response to an increased awareness of the risks posed by species movements, various international codes of practice, such as those developed by EIFAC, ICES and FAO (Turner, 1988; ICES, 1995; FAO Fisheries Department, 1997), and a range of regulations and laws have been introduced, greatly reducing the risk of unwise introductions. However, legislation regulating the movement of strains of species is much less strong. Rather than banning the introduction of exotic species for aquaculture purposes, it may be better to assess risks and benefits associated with introductions and, if judged appropriate, develop and implement plans for their responsible use. However, the risk assessment process is not infallible; it may identify and minimise risks but it cannot eliminate them. Bartley and Casal (1998) claimed that where there was sufficient information to assess impacts, most aquatic species introductions had had negative ecological but positive economic impacts. This implies that there are trade-offs to consider. However, again, caution should be exercised as any conclusions drawn are likely to be time frame-dependent.

Among the solutions that have been proposed to the problems posed by feral farmed aquatic animals, are the farming of local strains or of sterile fish. Farming of local stocks may be questioned on two counts. First, within very few generations farmed stock are likely to have gone through a number of selection bottlenecks, deliberate (e.g. selection for growth, shape, colour, etc.) or accidental (disease), thereby reducing heterogeneity. In other words, farmed local stocks rapidly begin to differ from their wild ancestors. Moreover, few farmers would countenance returning to the wild to seek broodstock, thereby foregoing the benefits of selective breeding on growth performance and introducing the risk of importation of disease to the farm. There are questions with regard to performance and economics of production of sterile fish as well as to their marketing. Triploid fish do not generally perform well in culture and producer organisations see little benefit of developing the technology in terms of marketability.

References

Alexis, M. (1997). Fish meal and fish oil replacers in Mediterranean marine fish diets. *Cah. Options Méditerr.*, 22: 183-204.

Anon. (1997). Disease carriers: Birds present health threat. *Fish Farm. News*, 5 (December 1997): 6-8.

Arrignon, J.C.V., Huner, J.V., Laurent, P.J., Griessinger, J.M., Lacroix, D., Gondouin, P. and Autrand, M. (1994). *Warm-water Crustaceans*. CTA/Macmillan, London.

Baccarani, E.M., Bona, F.V., Buriola, E. and Trotti, G.C. (1998). Larval cestode infections in the tench. *Parassitologia*, 40: 5.

Baltz, D.M. (1991). Introduced fishes in marine systems and inland seas. *Biol. Conserv.*, 56: 151-177.

Bartley, D. and Casal, C.V. (1998). Impacts of introductions on the conservation and sustainable use of aquatic biodiversity. *FAO Aquacult. Newsl.*, 20: 15-19.

Be'er, R. (1995). Protection of breeding pygmy cormorants *Phalacrocorax pygmaeus* hampered by harassment of wintering great cormorants *P. carbo sinensis* in Israel? *Corm. Res. Gr. Bull.*, 1: 47-48.

Bell, M.V., Henderson, R.J. and Sargent, J.R. (1986). The role of polyunsaturated fatty acids in fish. *Comp. Biochem. Physiol. Ser. B*, 83: 711-717.

Beveridge, M.C.M. (1988). Problems caused by birds at inland waters and freshwater fish farms. In: *Prevention and Control of Bird Predation in Aquaculture and Fisheries*, Welcomme, R. (ed.). EIFAC Technical Paper 51. FAO, Rome, pp. 34-73.

Beveridge M.C.M. (1996). *Cage Aquaculture.* 2nd Ed. Fishing News Books, Oxford.

Beveridge M.C.M., Phillips, M.J. and Macintosh D.C. (1997a). Aquaculture and the environment: The supply and demand for environmental goods and services by Asian aquaculture and the implications for sustainability. *Aquacult. Res.*, 28: 101-111.

Beveridge, M.C.M., Ross, L.G. and Kelly, L.A. (1994). Aquaculture and biodiversity. *Ambio*, 23: 497-502.

Beveridge, M.C.M., Ross, L.G. and Stewart, J.A. (1997b). The development of mariculture and its implications for biodiversity. In: *Marine Biodiversity: Patterns and Processes,* Ormond, R.F.G., Gage, J. and Angel, M. (eds). Cambridge University Press, Cambridge, pp. 372-393.

Black, K.D. (1998). The environmental interactions associated with fish culture. In: *Biology of Farmed Fish*, Black, K.D. and Pickering, A.D. (eds). Sheffield Academic Press, Sheffield, pp. 284-326,

Britton, R.H. and Johnson, A.R. (1987). An ecological account of a Mediterranean salina: The Salin de Giraud, Camargue (S. France). *Biol. Conserv.*, 42: 185-230.

Buzzi, M., Henderson, R.J., and Sargent, J.R. (1997). Biosynthesis of docosahexanoic acid in trout hepatocytes proceeds via 24-carbon intermediates. *Comp. Biochem. Physiol. Ser. B*, 116: 263-267.

Cezilly, F. (1992) Turbidity as an ecological solution to reduce the impact of fish-eating colonial waterbirds on fish farms. *Col. Waterbirds*, 15: 249-252.

Cowey, C.B. and Sargent, J.R. (1977). Minireview: Lipid nutrition in fish. Comp. *Biochem. Physiol. Ser. B*, 57: 269-273.
Dankers, N. and Zuidema, D.R. (1995). The role of mussels *Mytilus edulis* and mussel culture in the Dutch Wadden Sea. *Estuaries*, 18: 71-80.
Delgado, O., Grau, A., Pou, S., Riera, F., Massuti, C., Zabala, M. and Ballesteros, E. (1997). Seagrass regression caused by fish culture in Fornell's Bay, Menorca, Western Mediterranean. *Oceanol. Acta*, 20: 557-563.
Delgado, O., Ruiz, J., Pérez, M., Romero, J. and Ballesteros, E. (1999). Effects of fish farming on seagrass *Poseidonia oceania* in a Mediterranean bay: Seagrass decline after organic loading cessation. *Oceanol. Acta*, 22: 109-117.
Dell'Agnello, M. (ed). (1999). *Aquacultura: Qualità dell'Ambiente e del Produtto*. Scientifiche Italiene, Naples.
FAO Fisheries Department. (1997). *Aquaculture Development*. *FAO Technical Guidelines for Responsible Fisheries*, 5. FAO, Rome.
Furness, R.W. (1996). Interactions between seabirds and aquaculture in sea lochs, In: *Aquaculture and Sea Lochs*, Black, K.D. (ed.). Scottish Association for marine Science, Dunstaffnage Marine Laboratory, Oban, pp. 50-55.
García-Gómez, A. and Ortega-Ros, A. (1993). Revisión general del cultivo de nuevas especies piscícolas en el área mediterránea y experiencias realizadas en el Centro Oceanográfico de Murcia. *Informes Técnicos del Instituto Español de Oceanografia*, 141.
Genard, M., Masse, J. and Rigaud, C. (1993). Approche expérimentale de l'impact des oiseaux piscivores sur une pisciculture extensive littorale. *Bull. Fr. Piscic.*, 329: 231-243.
Gollasch, S., Minchin, D., Rosenthal, H. and Voigt, M. (eds) (1999). *Exotics Across the Ocean: Case Histories on Introduced Species*. Institute for Marine Science, University of Kiel, Germany.
Hansen, L.P., Jacobsen, J.A. and Lund, R.A. (1999). The incidence of escaped farmed Atlantic salmon *Salmo salar* L. in the Faroese fishery and estimates of catches of wild salmon. *ICES J. Mar. Sci.*, 56: 200-206.
ICES (1995). *ICES Code of Practice on the Introductions and Transfers of Marine Organisms*. International Council for the Exploration of the Sea, Copenhagen.
Keller, T., von Lindeiner, A. and Lanz, U. (1998) Cormorant management in Bavaria, Southern Germany – Shooting as a proper management tool? *CRG Bulletin*, 3: 11-14.
Le Breton, A., Grisez, L., Sweetman, J. and Ollevier, F. (1997). Viral nervous necrosis (VNN) associated with mass mortalities in cage-reared sea bass *Dicentrarchus labrax* (L). *J. Fish Dis.*, 20: 145-151.
McAllister, P.E. and Owens, W.J. (1992). Recovery of infectious pancreatic necrosis virus from the faeces of wild piscivorous birds. *Aquaculture*, 106: 227-232.
McGinnity, P., Stone, C., Taggart, J.B., Cooke, D., Cotter, D., Hynes, R., McCamley, C., Cross, T. and Ferguson, A. (1997). Genetic impact of escaped farmed Atlantic salmon (*Salmo salar* L.) on native populations: Use of DNA profiling to assess freshwater performance of wild, farmed and hybrid progeny in a natural river environment. *ICES J. Mar. Sci.*, 54: 998-1008.
McVicar, A.H. (1997). Disease and parasite implications of the coexistence of wild and cultured salmon populations. *ICES J. Mar. Sci.*, 54: 1093-1103.
Melotti, P., Loro, F. Roncarati, A. and Impiccini, R. (1994). Predation of sea bass (*Dicentrarchus labrax*) in the second year of intensive farming by fish-eating birds. *Riv. Ital. Aquacolt.*, 29: 23-30.
Melotti, P., Roncarati, A., Dees, A. and Mordenti, O. (1996). Impact of bird predation on the intensive rearing of seabass and sea bream. In: *Proc. Int. Workshop on Seabass and Sea Bream Culture: Problems and Prospects,* Verona (Italy), 16-18 October 1996, pp. 301-314.
Moyle, P.B. and Light, T.L. (1996). Biological invasions of freshwater: Empirical rules and assembly theory. *Biol. Conserv.*, 78: 149-161.
Rufino, R. and Neves, R. (1992). The effects on wader population of the transformation of salinas into fish farms. *Col. Waterbirds*, 15: 193-204.
Rufino, R., Araújo, A., Pina, J.P. and Miranda, P.S. (1984). The use of salinas by waders in the Algarve, south Portugal. *WSG Bull.*, 42: 41-42.
Sly, E. and Frankenberg, E. (1995). The conflict between cormorants and fishery in Israel. *Corm. Res. Group Bull.*, 1: 45-46.
Stickney, R.P., Hardy, R.W., Koch, K., Harrold, R., Seawright, D. and Masse, K.C. (1996). The effect of substituting selected oilseed protein concentrates for fish meal in rainbow trout *Oncorhynchus mykiss* diets. *J. World. Aquacult. Soc.*, 27: 57-63.
Tacon, A. (1999). Estimated global aquafeed production and aquaculture in 1997 and projected growth. *Internat. Aquafeed*, 2: 5.

Turner, G.E. (1988). *Codes of Practice and Manual of Procedures for Consideration of Introductions and Transfers of Marine and Freshwater Organisms*. EIFAC Occupational Paper, 23. FAO, Rome.

Welcomme, R.L. (1988a). *International Introductions of Inland Aquatic Species.* FAO Fisheries Technical Paper 294. FAO, Rome.

Welcomme, R.L. (ed.) (1988b). *Prevention and Control of Bird Predation in Aquaculture and Fisheries.* EIFAC Technical Paper 51. FAO, Rome.