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Bivalve aquaculture transfers in Atlantic Europe. Part B: Environmental impacts of transfer activities

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Abstract:

For centuries human populations have moved live shellfish around the world for consumption or aquaculture purposes; being relayed from their area of origin for growout or sale. This is in contrast to the inadvertent anthropogenic spreading of species via e.g. ballast waters. There are inherent risks associated with transfer of shellfish including introducing of alien species, diseases, pests, bacteria and viruses associated with the translocated species in addition to the potential impact on genetic integrity and biodiversity of local stocks. Many examples of severe ecological impacts have been documented worldwide owing to the intentional or unintentional translocation of animals. It is therefore important to develop risk reduction methods which have not yet been documented to be incorporated into current fish health or environmental legislation. This part of the study describes the impacts of transfer activities of cultured bivalve shellfish along the European Atlantic coast; identifies hitch hiker species, fouling organisms or infectious agents which can be translocated with a target species. Further, the study highlights the need for thorough, standard risk reduction measures designed to minimise the impact on ecosystems worldwide. In a companion paper details of actual transfer activities in Atlantic Europe are presented and all levels of legislation dealing with transfer activities on a global, regional and national scale are carefully reviewed.

Highlights

► We provide a full list of threats related to bivalve transfer activities. ► We draw the intention to the large spectrum of non-target species transferred with bivalves. ► We show the impact of transfers as potential vectors for the introduction of alien species. ► We provide detailed recommendations for a suitable risk assessment for impacts reduction.

1. Introduction

The intentional movement of shellfish around the world is an activity that has a long history (Wolff & Reise 2002). The objective is mainly economic; to develop a sustainable food supply, to replenish a depleted stock or to start a new culture. The translocation of different shellfish species includes early life stages from hatcheries, nursery sites or from the wild to new culture or wild fishery sites, often crossing national and ecosystem boundaries, creates the potential for negative impact on the environment. These impacts can occur through the introduction of shellfish and associated organisms which can include non-indigenous species, fouling organisms, potentially toxic algae, viruses, bacteria, disease agents, parasites, or the same species with a different genetic makeup. This can lead to an intermixing of wild and cultured or indigenous and introduced stocks with resultant impact: e.g. lower genetic integrity, subsequent poor recruitment and productivity, influenced by factors including sterilization, reduced fitness, meat yield and fecundity. Further, intermixing may have effects oncompetition, risk of predation, diversity and polymorphism, and on physiological and morphological traits (Dethlefsen 1975; Tiews 1988; Ambariyanto & Seed 1991; Camacho et al. 1997; Calvo-Ugarteburu & McQuaid 1998; Taskinen 1998; Wegeberg & Jensen 1999; Wegeberg & Jensen 2003; Desclaux et al. 2004). As described in detail in the companion Part A of this paper the movement of bivalves for aquaculture purpose can be differentiated into *transfers* and *introductions* (Beaumont 2000). According to this the movement of individuals outside the distributional range of the species is defined as an introduction, whereas a movement within species range would be referred as a transfer. In this study the focus is on the ecological effects of transfer activities.

Although most movements of shellfish are driven by economic reasons (Mortensen et al. 2006), stock transfers are also made because of shortfalls in local supply to replenish or enhance indigenous wild stocks. This reflects both the variable nature of recruitment to wild stocks; poor natural spat settlement onto artificial collectors or the inability to produce a consistent hatchery supply of seed, results in the lack of availability of high value commercially cultivated juvenile shellfish. Typical transfers of shellfish in Europe include native and Pacific oyster seed from hatcheries to nursery or adults and ongrowing sites, clam seed from hatcheries to ongrowing sites, scallops from natural spat collection sites to ongrowing sites, mussels from natural seed beds to ongrowing sites, and shellfish relayed for depuration or held at a dispatch centre prior to sale for human consumption.

Introductions as well as transfers, in the course of normal trade, have been responsible for the establishment of several harmful and nuisance non-native species including fouling organisms. Once established at a new locality these may continue to be moved by various means or by natural expansions of their range. McKindsey et al. (2007) provided detailed information on the implications of bivalve aquaculture and the introduction and spread of exotic species hitchhiking as fouling organisms (e.g. barnacles, bryozoans, marcroalgae, snails and even oysters). This study describes in contrast, the transfer and introductions of bivalve mollusc species and refers to their potential impacts; considering genetic effects, associated carrier parasites, pests, diseases, biotoxins, cysts, larvae and eggs. It also considers the introduction and spread of species' travelling with consignments, on and within the layers of bivalves' shells, in intervalval water, and within the tissues of the softbody. In many cases of introductions and transfers of bivalve molluscs for cultivation, no serious attempt has been made to avoid unwanted organisms. The export of half-grown Pacific oysters, *Crassostrea gigas*, spat from France to Ireland in 1993 is an outstanding example. Examination after deposit of the oysters, which had been certified "free from other species", revealed numerous other species: several fouling organisms, other bivalve species (which may potentially carry pathogens or parasites) and 67 species of phytoplankton, including dinoflagellate cysts (O'Mahony 1993; Minchin et al. 1993). Most of these accompanying organisms would perish with time or have no or minor effects on cultivated species in their new environment. However, sometimes new species may cause permanent or long-lasting fouling problems, competition for space or food, or in extreme cases – disease. While fouling macro-organisms may be relatively easy to find and identify if in appropriate numbers, microorganisms will be more troublesome.

In a companion paper (Mühlbauer et al. subm.) details of actual transfer activities in Atlantic Europe are presented and all levels of legislation dealing with transfer activities on a global, regional and national scale were carefully reviewed.

2. Effects of transfer activities

2.1. Transfer-effects of macro parasites and pests

Bivalve shells are a target of shell boring polychaets, such as *Polydora ciliata* inhabiting the shell of blue mussels, oysters, scallops and clams. This polychaete weakens shell strength (Kent 1981), increases energy requirements, impairs the overall health of the mussel (Kent 1979; Ambariyanto & Seed 1991), and harms in e.g. mussels the mantle tissues mainly responsible for reproduction (Wachter, 1979).Thus is classified as harmful to the host at least at high infestation rates (Michaelis 1978). A weakening in shell strength, the increased energy demand, the decline of reproductivity, and on occasions increased mortality, can severely impact both wild and cultivated mollusc populations. Other macro parasites inhabit organs and tissues of bivalves' softbody. From the German Bight for example, from two (affecting oysters) to ten (affecting mussels) different macro parasite species are reported to be common (Thieltges 2006). They belong to different phyla, inhabit various tissues and organs and cause a variety of symptoms. The intensity of the infestations can vary according to the conditions of the habitat. Blue mussels show the highest infestation rates at intertidal areas, followed by subtidal and offshore areas (Buck et al. 2005, Brenner et al. 2009). Other areas within the distributional range of blue mussels (*Mytilus edulis*) and close relatives (*Mytilus galloprovincialis, Mytilus trossulus*) show comparable numbers of parasite species, however, with a different species spectrum. Some parasite species are extensively found within the distributional range whereas others are restricted to relatively small areas. Thus, a movement of infested mussels amongst different areas and habitats to uninfected areas may support the transfer of parasites and pests between tidal levels e.g. from intertidal to subtidal areas, or from areas with high parasite diversity to areas showing a limited spectrum of species.

The role and effects of macro parasites on the health status of their hosts are still debated intensively. For *Mytilicola spp,* including *Mytilicola intestinalis and Mytilicola orientalis,* the characteristics range from being a pest with severe negative impacts (Odlaug 1946; Meyer & Mann 1950; Dethlefsen 1975), to only being a commensal organism feeding on unutilized fractions of the mussel's gut (Calvo-Ugarteburu & McQuaid 1998). Descriptions of other common parasitic species are more consistent.Metacercarias of trematods found in the digestive gland of blue mussels are described as reducing growth (Taskinen 1998; Calvo-Ugarteburu & McQuaid 1998), general health (Calvo-Ugarteburu & McQuaid 1998), reproductive ability (Coustau et al. 1993), and hamper feeding of the mussel (Thieltges 2006). Independently of the final evaluation of the resulting health effects of different parasite species, a spreading of these species should be generally avoided, whether by statute or industry voluntary codes of practice. Some parasites can impact commercial marketability and value by reducing shell strength or affecting the meat appearance and integrity of mussels (e.g. *P. ciliata*). Others like *M. intestinalis* cause aesthetic problems due to their markable colour and impressive size. And some just provoke distaste like the shell-inhabiting crabs of the genus *Pinnotheris*.

2.2. Transfer-effects of micro parasites (Protozoa) and diseases

In addition to macro parasites, bivalves are both host and vector of micro parasites, e.g. *Marteilia*, *Bonamia, Microcytos* and *Perkinsus* species. As these parasites severely affect the health of host shellfish, in contrast to macro parasites, they are listed under the mandate of the World Organisation of Animal Health (OIE 2010) and current shellfish health legislation (EC/2006/88). Prior to transfer activities, a shellfish area must be declared free of these listed diseases when destined for an area of equal or greater health status. For decades, outbreaks of e.g. Bonamiasis and Marteiliosis have led to dramatic losses in the French oyster industry and still a simple inspection for listed pathogens prior to transfer is not guaranteed to prevent the introduction, spread or containment of disease.

In the 1960s, *C. gigas*, was deliberately introduced from Japan to France and since then to much of the coastal regions of Europe. It was seen as a disease free, good growing alternative to *Ostrea edulis* and *Crassostrea angulata* whose stocks suffered severely under *Bonamia* and *Marteila* infections. The Pacific oyster is scientifically proven non-susceptible to *Bonamia* and so movements were routinely made around Europe with little control. In the 1990s, a transfer of *C. gigas* was made from France to

Ireland and deposited in the sea, prior to inspection for susceptible or hitch hiker species. After the event, non indigenous species and indigenous species capable of transmitting serious disease were found; including the pest *M. orientalis,* and *O. edulis* which is capable of transmitting *Bonamia* (Minchin 1996).

Further, there is a lack of knowledge on the life cycles of even the best known bivalve pathogenic agents. *Marteilia refringens* seem to go through several stages in a complex life cycle (Grizel et al. 1974; Perkins 1976). In Mortensen (2000) *O. edulis*, were kept free from *M. refringens* in tanks using water from the wild oyster beds. However, these oysters became immediately infected once moved out on oyster beds by some unknown intermediate host or stage of *M. refringens* present in the environment. The most serious oyster pest in Europe, the protozoan *Bonamia ostreae* also illustrates the problem. At first sight it seems not to have a complicated life cycle like *Marteilia*. *Bonamia* propagates by binary fission until the host cell, the oyster haemocyte, bursts. But despite a number of studies, there remain unanswered questions. It is not known why small oysters are unaffected, but the oyster died due to the parasite when they approach sexual maturity. A life cycle with a phase in the ovarian cycle has been suggested (van Banning 1990), but it is still not fully understood. Also, the host range of many agents is largely unknown, and extensive studies are necessary to identify potential host species. Thus, it remains unknown which bivalve species may be susceptible, which species might be vectors, in which stage the parasite may be dispersed, or which species might be intermediate hosts.

There is a tendency to link the pathogenic agents to the species in which they are first described, but this may often be wrong. When the protozoan *Microcytos mackini* was identified as the causative agent of Denman Island Disease of Pacific oysters, *C. gigas* in British Columbia, Canada, the agent was first linked to this oyster species, but later similar organisms were observed also in flat oysters, *O. edulis*, and *Olympia* oysters, *O. lurida*, in the US, and Sydney rock oysters, *Saccostrea commercialis*, in Australia. The causative agents were identified as two different Microcytos species (Farley et al. 1988). Later experiments showed that *M. mackini* was pathogenic also for the oysters *Crassostrea virginica, O. edulis and O. lurida* (Bower et al. 1997). The example illustrates that what may seem as one disease in one species may appear in different areas, and be caused by different, but related parasites, which themselves may be pathogenic for different host species. This complicates the one disease-one host-one area management approach, which is commonly applied. Even when we have documented that a specific agent is actually pathogenic, there are often great uncertainties concerning the infectious dose of agents, influence of environmental factors on disease, etc.

2.3. Transfer-effects of pathogenic agents, bacteria and viruses

The survival of bacteria in seawater and their presence in bivalves varies with exposure to environmental factors such as temperature, salinity, organic loading and is influenced on seasonal and spatial scales (Hernroth 2003). The bivalves' response towards ingested microbes is to eliminate them. However, it has been shown that e.g. *Salmonella typhimurium* can survive more than two weeks after being injected into the circulating system of mussels (Hernroth 2003). *Salmonella* species can cause enterocolitis, enteric fevers such as typhoid fever, and septicemia with metastatic infections in humans. Seawater is the natural habitat of the *Vibrio* bacteria, feared as pathogens in fish and shellfish (Shao 2001). *Vibrio* can cause severe infections in humans after consumption of raw or undercooked shellfish and contaminated food. A special hazard is caused by *Vibrio vulnificus*, where severe infections can occur through skin lesions (Blake et al. 1979). *Vibrio* species are associated with both human health problems and with the pathogenicity and mortality of mollusc species. In France, the rearing of *C. gigas* is the main aquaculture activity and has recurrently suffered large scale summer mortality phenomenon for the last 15 years. Several *Vibrio* strains belonging to *V. aestuarianus* and *V. splendidus* have been found to be associated with diseased juvenile oysters suffering from the summer mortality syndrome. Most of these strains exhibit also harmful effect when living bacteria or their extracellular products are experimentally injected to healthy oysters confirming their pathogenicity.

Like bacteria, viruses are predominantly concentrated in the digestive glands, but can also be absorbed through the gills of bivalves (Abad et al. 1997). Certain viruses such as the Norovirus are even more persistent and can remain infectious for weeks to months in seawater or in sediment

(Gantzer et al. 1998). Although they are inherently unable to multiply in bivalves, shellfish are efficient vehicles for transmission of pathogenic viruses to humans. Epidemiological studies have revealed that human enteric viruses are the most common pathogens transmitted by consumption of bivalve shellfish (Lees 2000; Lipp & Rose 1997). Among these, hepatitis A virus (HAV) is the most serious viral infection linked to the consumption of bivalves. In Italy, estimates suggest that approximately 70 % of HAV cases are caused by shellfish consumption (Salamina & D' Argenio 1998). The relatively long incubation period following initial infection (average 4 weeks), complicates the traceability of the viral source. Thus, HAV infections caused through shellfish consumption are probably underreported or even remain undiscovered.

Norovirus and serotypes of the adenovirus group are associated with gastroenteritis. These viruses have been recorded in seawater and shellfish in many different countries, such as Greece, Spain, Sweden and the UK (Formica-Cruz et al. 2002). In particular overall viral infections caused by the Norovirus (gene group II) have shown a remarkable increase, as registered by the Robert-Koch Institute (RKI 2000). This increase, may be because Norovirus infections must be reported by law. However, the rapid course of the illness within a few hours complicates appropriate counter measures.

In general, viruses can be surprisingly inert. After the finding of the fish pathogenic infectious pancreatic necrosis virus (IPNV) in scallops, *Pecten maximus* (Mortensen et al. 1990), the subsequent study of the fate of IPNV in scallops (Mortensen et al. 1992, Mortensen 1993) showed that the virus was taken up during filtration, persisted for long periods of time, and was shed into the water by contaminated scallops. No viral propagation was found, and in nature, the virus excreted from contaminated bivalves would rapidly be diluted in seawater. Scallops and other bivalves should probably still be considered potential vectors also of fish pathogenic viruses. One example is the virus causing gill disease, which eradicated the susceptible populations of Portuguese oyster, *C. angulata*, from the French coast, while the resistant Pacific oyster, *C. gigas,* remained only slightly affected by the disease (Comps et al. 1976; Comps 1988). It has been hypothesised that *C. gigas*, which was actually introduced to France just before the first outbreaks, was actually the vector, being adapted to the virus through generations of coexistence in Japan. The risk of disease transmission becomes greater when there are true biological vectors, where a pathogenic agent maintains its normal function and even propagates. Considering the above-mentioned coexistence between any animal and its microorganisms, the microecological balance may be disturbed during an introduction or transfer. From the introduced scallop's point of view, there may be unknown reservoirs, intermediate or alternative hosts of pathogenic agents in its "new" environment (Mortensen 2000). From the point of view of the inhabitant of the recipient environment, the "newcomer" may pose a threat, bringing new microorganisms, which are potentially pathogenic agents for them.

In a recent example, oyster spat from hatcheries contaminated with the Oyster Herpes Virus (OsHV-1), was moved routinely for years around France and further afield uncontrolled, with little attention to inspection, consignment carrier status, or for the presence of hitch hikers. Lately, an extremely pathogenic variant, OsHV-1 µvar, was identified as the causative agent of high mortality especially in France (Segarra et al. 2011), which prompted the EC Commission to consider the variant as an emerging disease (EC) 350/2011.

2.4. Transfer-effects of biotoxins, cysts, larvae and eggs

The main food source for bivalves is phytoplankton and thus the potential for accumulating algal toxins is high. Several human diseases have been reported to be associated with many toxin-producing species of dinoflagellates, diatoms, nanoflagellates and cyanobacteria that occur in the marine environment (CDC 1997). Marine algal toxins become a problem primarily because they may concentrate in shellfish and fish that are subsequently eaten by humans (CDR 1991; Lehane 2000). These toxins cause severe syndromes of poisoning (e.g. Amnesic Shellfish Poisoning (ASP), Diarrheal Shellfish Poisoning (DSP), Paralytic Shellfish Poisoning (PSP), Neurotoxic Shellfish Poisoning (NSP)) and, on occasion, death. In addition to accumulating poisons, filtering bivalves can function as a vector for the distribution of reproductive cysts of toxin-producing algal species. These cysts may survive in unfavourable conditions for years buried in the sediments (Tillmann & Rick 2003) and can, after being re-suspended and translocated in e.g. the intervalval water of molluscs, build up new populations in formerly unaffected areas (Mons et al. 1998). Thus, this type of transfer may result

in human health risks, fishery and culture closures and commercial losses. The transportation of toxin-producing algal species and their resting cysts, either in a ship's ballast water or through the movement of shellfish stocks from one area to another, provides a possible explanation for the increasing trend of harmful algal blooms (Hallegraeff 1995; McMinn et al. 1997). As part of the controls to protect public health, European regulation requires a monitoring programme of shellfish relaying and production areas to be established to check for the possible presence of toxin producing plankton in the water and biotoxins in the shellfish flesh (EC Regulation 854/2004).

Comparable to the diversity of species living as commensals on the shells of bivalves, numerous species are present in their intervalval water. Many species from different phyla such as bacteria, viruses, fungi, or ciliophora use bivalves as a host, whereas others (or other species from the same mentioned phyla) are filtered actively as food (e.g. micro algae) or enter the molluscs accidently through the incurrent water flow. Depending only on the size of organism many species and especially their larval stages, cysts or eggs can be present in bivalves. Since live bivalves are usually translocated dry, trapped species can travel together with their temporary host over large distances. For example, egg capsules of the American oyster drill, *Urosalpinx cinerea*, have been found in the Oosterschelde, an area of shellfish culture in The Netherlands. Most probably *U. cinerea* was introduced within transfered shellfish from south-east England (ICES 2008).

2.5. Genetic effects of transfers

It is becoming increasingly important to identify species being transfered or introduced, not simply morphologically, but using appropriate statistically significant screening, including specific and sensitive molecular tests. It is also recognised that the gene pool of the broodstock used to provide progeny for cultivation or augmentation of wild, should not act as vectors of disease, compromise or reduce genetic integrity of indigenous populations, result in interbreeding, reduced reproduction or introduce traits not conducive to growth and survival. To predict the genetic consequences of transfers, information on genetic composition of species to allow their identification and differences between source and recipient populations is vital (Beaumont 2000). This may be expressed by morphological, allozyme and DNA based data on genetic differentiation of populations and sub-species.

Other considerations are the numbers of individuals transfered and whether they are wild stock or a hatchery product. Loss of genetic diversity is difficult to avoid in hatchery conditions although there are also ecological advantages using disease-free or sterile hatchery seed. Examples are given in Beaumont (2000) on how mitochondrial DNA data indicate significant genetic consequences of the introduction of *Argopecten irradians* from the USA to China, and *Patinopecten yessoensis* introduced from Japan to Canada. Beaumont (2000) recommends that potential risks and consequences of hybridisation should be experimentally assessed before introductions of scallops are carried out. However, hybridisation is unpredictable and can lead to loss of genetic diversity or the breakdown of co-adapted gene complexes, resulting in a poor commercial product. The use of sterile triploid scallops for introductions to avoid hybridisation and reduce ecological impact has merit but reversion to diploidy may occur. There is also the risk that introductions breeding with indigenous stock could result in reduced future fecundity.

Crassostrea gigas was introduced in Europe as an alternative to the Portuguese oyster (*C. angulata*) following the viral disease that caused the collapse of the Portuguese oyster populations. Currently there is contact between the species worldwide; between France and the south of Portugal and between Japan and Taiwan. In these regions hybrids have been found. This hybridisation has an impact on the *C. angulata* population in Southern Europe. Pacific oyster spat is mainly obtained from settlement from the wild, however about 20 % of pacific oyster spat is derived from hatcheries. Hatcheries mainly produce triploid spat, which is not yet considered as a safe genetic confinement tool, as triploids do occasionally breed. The effect of the partial sterility of triploids is poorly known. Another threat to wild populations is the use of tetraploid broodstock if they escape from quarantine, as their fitness relative to diploids and the impact of their breeding with diploids is still unknown (GENIMPACT 2007). Another impact has recently been recognised resulting from the reproduction and spread of Pacific oysters in the wild, invading ecosystems to replace indigenous species and causing a problem to shellfish farmers because of extensive wild and uncontrolled spatfall. This non-

indigenous species which was originally introduced to enhance and expand aquaculture production has become established in many European countries to the extent of now being considered a pest, not only to farmers and wild fisheries, but also to leisure industries by impacting beaches and pier areas.

The European flat oyster (*O. edulis*) occurs naturally from Norway to Morocco in the North-Eastern Atlantic and in the whole Mediterranean basin. The species was also introduced in the United States, from Maine to Rhode Island (1930's and 40's) and in Canada (about 30 years ago). Mediterranean flat oysters have more genetic variability than the Atlantic population. The North American populations were derived from the Atlantic population. Most flat oysters are grown from wild captured seed but e.g. in the UK and Ireland hatcheries can produce flat oyster spat. Hatchery cultured spat can result in a reduced genetic variability, if care is not taken in selecting broodstock. This can result in reduced variability of the natural populations. The technology exists to produce polyploid flat oysters, however this resource is not currently utilised. No large scale selective breeding programmes have been initiated for *O. edulis*. However, some experiments to improve resistance to *B. ostreae* have been carried out. Results show a higher survival rate and a lower prevalence of this parasite in selected stocks, but also a reduced genetic variability in mass selected populations (Lapègue et al. 2006).

The mussel species *M. edulis* and *M. galloprovincialis* are widely distributed within Europe. *Mytilus edulis* is found to be homogeneous throughout its range while *M. galloprovincialis* is genetically subdivided into a Mediterranean and an Atlantic group. *Mytilus trossulus* also exists in discrete areas. In places where two or more of these species occur together, hybrids are found. Information on the distributions of mussel species and their hybrids is gradually improving (Dias et al. 2008a; 2008b). The potential influence of environmental conditions on growth and shell morphology makes it difficult to distinguish the species and their hybrids based on shell shape alone. Recent research on the distribution of the *Mytilus* species in Europe has been greatly facilitated by molecular tools which, based on the animal's DNA, are able to reliably distinguish between species and hybrids in both wild and cultivated populations (Dias et al. 2008b).

Mytilus galloprovincialis was identified in cultivation areas in Scotland and *M. trossulus* alleles occur at the Irish east coast (Kijewski et al. 2009) in waters which were formerly described as inhabited by pure *M. edulis* populations (Gossling et al. 2008). This has raised questions relating to the risks associated with transfers of seed and the consequential sustainability of blue mussel cultivation in certain countries. Forensic investigation of the occurrence of *M. trossulus* in a few sea lochs in Scotland indicates that the distribution of *M. trossulus* appears to be consistent with the species having been moved from place to place during transfers of mussel stock for cultivation purposes. Where *M. trossulus* has been moved out of the original Scottish site to areas of full strength salinity seawater, *M. trossulus* have reportedly died and not spread through natural settlement. It has not yet been found in wild populations, even where adjacent cultivation ropes contain large proportions of *M. trossulus*. The majority of mussel production sites in Scotland produce *M. edulis* and work is ongoing to systematically manage out *M. trossulus* from the Scottish index site to minimise any risk of its spread within Scottish waters.

Further, the three main cultivation methods for mussels (bottom culture, suspended culture and pole culture (or bouchot method) have their own specific growth requirement. Therefore, there may be a genetic impact due to genotype-specific mortality in areas where aquaculture is the major source of mussel biomass.

2.6. Transfer-effects on biodiversity

Many non-native species introductions have not been registered and may have had no impact on receiving environments (Gollash 2004). However, many introductions into the marine environment have been classified as invasive (Kettunen 2009). The impacts identified have been wide ranging and include impacts on native habitats and species. More specifically, it has been documented that species can have direct impacts by excluding native species and thereby reducing biodiversity. The introduction and transfer of marine molluscs from fisheries and aquaculture includes the risk of transporting competitors, predators, parasites, pests and diseases which have compromised intended molluscan culture and wild fisheries.

The expansion of *C. gigas*, throughout northern latitudes of Europe has been well documented (Reise 1998; Drinkwaard 1999a; 1999b; Smaal et al. 2005). The spread has been rapid and has resulted in very high recruitment of the oysters in marine habitats. In some areas the diversity of species associated with *C. gigas* has been demonstrated to be higher than that of ambient habitats (Kochman et al. 2008). While species diversity may be comparable or higher on short spatial scales, the invasive nature of *C. gigas* is such that habitat heterogeneity is greatly reduced over large spatial scales. There is the additional risk of transfer of the highly pathogenic oyster herpes virus with the potential of causing high mortality in naïve wild and cultivated populations of *C. gigas.*

The manila clam, *Ruditapes philippinarum*, originated from Asia, was introduced into France in the 1980's for aquaculture purposes, including Arcachon Bay. For economic reasons, this aquaculture was unsuccessful and was rapidly abandoned; however, the species subsequently found good environmental conditions to reproduce naturally and expanded in the wild. Ten years later, this exotic clam species was more abundant than the native one, *Ruditapes decussatus*. This situation can be explained by superior recruitment and rapid growth to outperform the indigenous species. Since 1992, the biomass of the introduced clam *R. philippinarum* has been exploited by fishermen (Dang et al. 2010).

Still uncertain is, how the Manila clam out-competes the indigenous species and contributes to the modification of biodiversity in Arcachon Bay. Both species colonize the same habitat and with time, the ratio between the 2 species was modified to the benefit of the Manila clam. The competition is probably not direct for space and food but associated with the fishing activity. The stock exploitation impacts more drastically the European species because of it low capacity to recolonize the habitat compare to those of the indigenous species (Auby 1993).

3. Recommendations

There is a need for comprehensive health surveillance strategies involving procedures to systematically look for early signs and assess the adverse effects on the health-status of a country. The priority should be prevention and to establish the absence of a problem, but have the facility to detect one if it exists. Therefore, it is necessary to develop a plan to evaluate and establish the status of a country or area and be able to control a problem if it occurs, e.g. via surveillance and eradication if a disease or invasive organism is found. This may be undertaken by voluntary industry codes of practice or by statute, depending on the status of each country and what it aims to control. It is essential to identify the risks associated with aquaculture production and to introduce methods to minimise and control them. These may be associated with the introduction of disease, pests, parasites, fouling organisms or adverse effects associated with movements or transfers of bivalve shellfish, equipment and sea water associated with the transfers.

The requirements, legal or otherwise, depend on their value; the impact on sustainability and whether controls are considered to be possible. Measures should be in place to measure their success and to point to further steps, if deemed necessary. It is vital to involve industry, policy makers and scientists in the development of all strategies and procedures to ensure that each embrace them and contribute effectively to their success. In development of a new Animal Health Law (SANCO/7221/2010 working document) regarding movements of animals for trade and measures for disease control, the conclusions of the chief veterinary officers emphasise the importance of surveillance as a key element of animal health policy. They give priority to preventive approaches, early detection and quick response; notification which in turn enables timely control and eradication when feasible. Also, clear objectives of such a system should be established to generate and manage reliable, transparent and accessible epidemiological & surveillance data connected into an appropriate informatics system.

Risk-based animal health surveillance under Council Directive 2006/88/EC is designed to prevent and control certain diseases in aquaculture animals and products; including measures on suspicion of, or during an outbreak of disease. Member States must ensure that a risk-based animal health surveillance scheme is applied in all farms and mollusc farming areas. The aim of the schemes is to identify and mitigate risks, instigate good site biosecurity measures, to detect any increased mortality and the presence of listed or emerging diseases- where susceptible species are present.

4. Conclusion

Moving shellfish within and between countries and ecosystems, poses a high risk of ecological impact, to genetic integrity and to the introduction and spread of invasive species and pathogenic agents. There should be a presumption against routine introductions and transfers of molluscan shellfish. Transfers should only occur through necessity, e.g. in the promotion of free trade and only be made following a full risk assessment to demonstrate negligible risk. As global communication continues to develop it becomes increasingly important to develop a more dynamic and transparent global approach, to controls with standardised guidelines, including aspects such as risk assessment, management advice, and the identification and application of research goals.

In general, all possible alternatives on the local level e.g. employing hatchery or spat collection methods should be investigated before consideration of transfers as a last resort. If there are good commercial reasons for the transfer of a species, a robust standard of risk assessment should be applied, prior to release, to ensure that ecosystems are protected. Risk based surveillance is now an animal health requirement under Council Directive (EC) 2006/88 for the prevention and control of certain diseases, and models produced by each country should be designed to identify and quantify risks of disease introduction and spread. Transfers of shellfish are made routinely at all levels, by countries of differing environmental and disease status, highlighting the real risks of introducing listed and non-listed pests, parasites and diseases. There is a need for continued coordination in the development and application of legislation and codes of practice within and between countries; to minimise introduction and spread of invasive species and pathogenic organisms. Several tools, e.g. ICES Codes of Practice (ICES 2005), EC regulations, The Animal Health Code from Office International des Epizooties, and common veterinary practice are designed in order to assess risk, and avoid introductions of pathogenic agents and exotic species with the consignments. However, even if all guidelines and recommendations are followed, it is impossible to predict all possible effects of transfers and introductions, and to predict which disease problems may follow. The spread of pathogens frequently occurs ahead of the diagnostics. Learning from introductions and transfers of other bivalve species is therefore essential, to enable a proper risk assessment.

The strategy and principles to be followed by EC Directives involve; such that the burden to the public and private sectors is proportionate, finding the balance between control of non-wanted organisms and over-regulation and ensuring that regulation and surveillance is based on a transparent assessment of risk. An essential part in the development of any risk based assessment model is to ensure that it accurately identifies and quantifies those risks associated with all farms within a zone and provides early detection of possible impacts. Risk assessment requires regular review as industry practices evolve, increasing or decreasing risk on farm sites. Each farm is to receive a ranking (high, medium or low) based on criteria developed at a surveillance work stream workshop, frequency of inspection to be determined by the ranking of each site (Annex III of (EC) 2006/88).

A full risk assessment should include possible effects of diseases (parasites, viruses and bacteria), genetic contamination and hitch hiking species. The risk assessment should be undertaken to ensure safety to ecosystems, as the long term environmental and financial costs from introductions is unquantifiable in the long term. Consultation on applications should be vigorous, be universally applied and be objective; and there should be a presumption against them, unless good scientific evidence proves otherwise. Further, consideration should be given to the risk to native stocks from interbreeding and to the resultant progeny invading ecosystems being possibly infertile, creating an imbalance within an ecosystem. At the final destination a proper quarantine facility should be established to monitor transfered bivalves. The facility must be authorised as an Aquaculture Facility and all movements of live animals into the facility are to be recorded. If high risk were assessed, consideration should be given to growing the animals through the F1 generation to assess reproductive behaviour and the danger of disease transmission, prior to release.

However, there is little health protection against non listed species where there is little scientific knowledge of their impact or susceptibility to diseases. A full risk assessment would require a complete list of all non-target species to identify non-native species that might be imported into an area with a consignment of shellfish. For this goal it will be necessary to have a good knowledge of the

marine biodiversity in shellfish areas and to be able to distinguish exotic species from indigenous fauna and flora. So in this context it is important to have monitoring networks. Monitoring programs developed for other purposes (i.e. for microbiological contamination, toxins and for EU Directives as water framework directive and marine strategy directive) can provide useful information and with some limited adjustments could be improved to include exotic species recording.

However, the presence of “usually harmless – potentially harmful” organisms leads us to the problem on the existence of “stowaways”, and the action of mechanical vectors. One organism will always carry another, and it seems impossible to obtain “clean” animals, in spite of long quarantines. An example of stowaways is hidden organisms in a consignment of bivalve spat. Frequently, batches contain more species than those they are supposed to contain, even if the batches have been (roughly) inspected, cleaned and graded. Mechanical vectors are passive carriers, which are not needed for the propagation of the species being carried. So even if all potential precautions were conducted properly the effects of transfers and introductions of bivalve molluscs are to some extent unpredictable. Moving molluscs, there is a risk of introducing pathogenic agents or of disturbing the balance between potentially pathogenic agents and host species in the recipient ecosystem.

Overall, impact rather than financial considerations should be the prime concern. If a company wishes to profit from a transfer or introduction it should be prepared to undertake the proper scientific assessment of risk prior to release, as long term impacts can be serious and wide-ranging. Here, the guidelines on best environmental practice (BEP) for the regulation and monitoring of marine aquaculture as defined in the Monitoring and Regulation of Marine Aquaculture Programme (MARAQUA) (Read et al. 2001) for the European Union as well as for all countries defined by the FAO (FAO 1999), should be taken into account. These guidelines also include best available techniques (BAT) and best management practices (BMP).

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526 **References**
527
528 Abad, F.X., Pinto, R.M., Gajardo, R., Bosch, A., 1997. Viruses in mussels: public health implications
529 and depuration. J. Food Prot. 60, 677-681.
530 Ambariyanto, Seed, R., 1991. The infestation of *Mytilus edulis* Linneaus by *Polydora ciliata* (Johnston)
531 in the Conwy estuary, North Wales. J. Mollusc. Stud. 57, 413–424.
532 Auby, I., 1993. Evolution de la richesse biologique du bassin d`Arcachon. Société Scientifique
533 d'Arcachon, Laboratoire d'Océanographie Biologique, Report pp462.
534 Beaumont, A., 2000. Genetic considerations in transfers and introductions of scallops. Aquacult. Int. 8,
535 493-512.
536 Blake, P.A., Merson, M.H., Weaver, R.E., Hollis, D.G., Heublein, P.C. 1979. Disease caused by a
537 marine *Vibrio*: clinical characteristics and epidemiology. N. Engl. J. Med. 300, 1-5.
538 Bower, S.M., Hervio, D., Meyer, G.R. 1997. Infectivity of *Microcytos mackini*, the causative agent of
539 Denman Disease in Pacific oysters *Crassostrea gigas*, to various species of oysters. Dis. Aquat.
540 Org. 29, 111–116.
541 Brenner, M., Ramdohr, S., Effkemann, S., Stede, M., 2009. Key parameters for the consumption
542 suitability of offshore cultivated mussels (*Mytilus edulis*) in the German Bight. Eur. Food Res.
543 Technol. 230, 255-267.
544 Buck, B.H., Thieltges, D.W., Walter, U., Nehls, G., Rosenthal, H. 2005. Inshore-offshore comparison of
545 parasite infestation in *Mytilus edulis*: Implications for open ocean aquaculture. J. Appl. Ichthyol.
546 21(2), 107-113.
547 Calvo-Ugarteburu, G., McQuaid, C.D., 1998. Parasitism and invasive species: effects of digenetic
548 trematodes on mussels. Mar. Ecol. Prog. Ser. 169, 149–163.
549 Camacho, A., Villalba, A., Beiras, R., Labarta, U., 1997. Absorption efficiency and condition of cultured
550 mussels (*Mytilus edulis & M. galloprovincialis*, Linneaus) of Galicia (NW Spain) infected by
551 parasites *Marteilia refringens* (Grizel et al.) and *Mytilicola intestinalis* (Steuer). J. Shellfish Res. 16,
552 77–82.
553 CDC, 1997. Results of the public health response to *Pfiesteria*-Workshop – Atlanta, Georgia,
554 September 29–30, 1997. Morbidity and Mortality Weekly Report 46(40), 951–952.
555 CDR, 1991. Communicable Disease Report. Paralytic shellfish poisoning 1(22), 1.
556 Comps, M., 1988. Epizootic diseases of oysters associated with viral infections. In: Ed. W.E. Fisher
557 (Ed.) Disease Processes in Bivalve Molluscs, American Fisheries Society Special Publication 18,
558 Bethesda, USA, pp. 23–37.
559 Comps, M., Bonami, J.-R., Vago, C., Campillo, A., 1976. Une virose de l'huitre Portugaise
560 (*Crassostrea angulata*). C.R. Acad Science, Paris, 282(D22), 1991–1993.
561 Coustau, C., Robbins, I., Delay, B., Renaud, F., Mathieus, M., 1993. The parasitic castration of the
562 mussel *Mytilus edulis* by the trematode *Prosorpynchus Squamatus*: Specificity and partial
563 characterization of endogenous and parasite induced anti-mitotic Activities. Comp. Biochem.
564 Physiol. 104(A), 229-233.
565 Dang, C., de Montaudouin, X., Gam, M., Paroissin, C., Bru, N., Caill-Milly, N., 2010. The manila clam
566 population in Arcachon Bay (SW France): Can it be kept sustainable? J. Sea Res. 63, 108-118.
567 Desclaux, C., de Montaudouin, X., Bachelet, G., 2004. Cockle *Cerastoderma edule* population
568 mortality: role of the digenean parasite *Himasthla quissetensis*. Mar. Ecol. Prog. Ser. 279, 141–
569 150.
570 Dethlefsen, V., 1975. The influence of *Mytilicola intestinalis* Steuer on the meat content of the mussel
571 *Mytilus edulis* L. Aquaculture 6, 83–97.
572 Dias, J., Snow, M., Davies, I., 2008a. Understanding the distribution of mussels (Mytilus species) in
573 cultivation and wild populations in Scotland. Fish Farmer, Sept/Oct, 26-27.
574 Dias, P.J., Sollelis, L., Cook, E.J., Piertney, S.B., Davies, I.M., Snow, M., 2008b. Development of a
575 real-time PCR assay for detection of Mytilus species specific alleles: Application to a sampling
576 survey in Scotland. J. Exp. Mar. Biol. Ecol. 367, 253–258.
577 Drinkwaard, A.C., 1999a. Introductions and developments of oysters in the North Sea area: a review.
578 Helgoland Wiss. Meer. 52, 301–308.

579 Drinkwaard, A.C. 1999b. History of cupped oyster in European coastal waters. Aquaculture Europe 15
580 (7), 14–41.
581 EC Directive (EC), 2006/88. Official Journal of the European Union 24.11.2006 (OJ No L328/14
582 24.11.2006).
583 EC Regulation (EC), 854/2004. Regulation of the European Parliament and of the Council of 29. April
584 2004 laying down specific rules for the organisation of official controls on products of animal origin
585 intended for human consumption.
586 EC Regulation (EC), 350/2011. Amending Regulation (EC) No 1251/2008 as regards the placing on
587 the market requirements for consignments of Pacific oysters intended for Member States or parts
588 thereof with national measures regarding ostreid herpes virus 1 µvar (OsHV-1 µvar) approved by
589 Decision 2010/221/EU
590 FAO, 1999. Food and Agriculture Organisation of the United Nations. Incentives systems for natural
591 resources management: The role of indirect incentives. Report No. 99/023 IFAD-RAF, FAO,
592 Rome, 19 pp.
593 Farley, C.A., Wolf, P.H., Elston, R.A., 1988. A long-term study of “micorcell” disease in oysters with a
594 description of a new genus, *Microcytos* (g.n.), and two new species, *Microcytos mackini* (sp.n.)
595 and *Microcytos roughleyi* (sp.n.). Fish Bull, 86(3), 581–593.
596 Formica-Cruz, M., Tofino-Quesada, G., Bofill-Mas, S., Lees, D.N., Henshilwood, K., Allard, A.K.,
597 Conden-Hansson, A.–C., Hernroth, B.E., Vantarakis, A., Tsibouxi, A., Papapetropoulou, M.,
598 Furones, M.D., Girones, R., 2002. Distribution of human virus contamination in shellfish from
599 different growing areas in Greece, Spain, Sweden and the United Kingdom. Appl. Environ.
600 Microbiol. 68, 5990-5998.
601 Gantzer, C., Dubois, E., Crance, J.M., Billaudel, S., Kopecka, H., Schwartzbrod, L., Pommepuy, M., Le
602 Guyader, F., 1998. Influence of environmental factors on the survival of enteric viruses in
603 seawater. Acta Oceanologia 21, 983-992.
604 GENIMPACT, 2007. Genetic impact of aquaculture activities on native populations, in: Svåsand T.,
605 Crosetti D., García-Vázquez E., Verspoor E., (Eds), Genimpact final scientific report (EU contract
606 n. RICA-CT-2005-022802), 176 pp.
607 Gollash, S., 2004. A global perspective on shipping as a vector for new species introduction.
608 Presented at the 13th International Conference on Aquatic Invasive Species, Ennis, Co Clare,
609 Institute of Technology, Ireland.
610 Gosling, E., Doherty, S., Howley, N., 2008. Genetic characterization of hybrid mussel (Mytilus)
611 populations on Irish coasts. J. Mar. Biol. Assoc. U.K. 88, 341–346.
612 Grizel H., Comps M., Cousserans F., Bonami J.-R., Vago C., 1974. Pathologie des invertébrés. Etude
613 d’un parasite de la glande digestive observée au cours de l’épizootie actuelle de l’huitre plate.
614 Comptes Rendus Academie des Science Paris 279(D), 783–784.
615 Hallegraeff, G.M., 1995. 1. Harmful algal blooms: a global overview, in: Hallegraeff, G.M. et al., (Eds.),
616 Manual on Harmful Marine Microalgae, IOC Manuals and Guides No. 33. UNESCO, pp. 1-22.
617 Hernroth, B., 2003. Factors influencing bactericidal activity of blue mussel (*Mytilus edulis*) haemocytes
618 against *Salmonella typhimurium*. Fish Shellfish Immunol. 14, 93-104.
619 ICES, 2005. International Council for the Exploration of the Sea. Code of Practice on the Introduction
620 and Transfers of Marine Organisms, 30 pp.
621 ICES, 2008. International Council for the Exploration of the Sea. Report of the Working Group on
622 Introduction and Transfers of Marine Organisms (WGITMO), 12.–14. March 2008, Copenhagen,
623 Denmark. ICES CM 2008/ACOM: 52: 130 pp.
624 ICES, 2011. International Council for the Exploration of the Sea. Report of the Working Group on
625 Marine Shellfish Culture (WGMASC), 5–8 April 2011, La Trinité-sur-Mer, France, ICES CM
626 2011/SSGHIE:08: 98 pp.
627 Kent, R.M.L., 1979. The influence of heavy infestations of *Polydora ciliata* on the fleshcontent of
628 *Mytilus edulis*. J. Mar. Biol. Assoc. U.K. 59, 289-297.
629 Kent, R.M.L., 1981. The effect of *Polydora ciliata* on the shell strength of *Mytilus edulis*. Journal of the
630 international Council for the Exploration of the Sea 39, 252-255.
631 Kettunen, M., Genovesi, P., Gollasch, S., Pagad, S., Starfinger, U., ten Brink, P., Shine, C., 2009.
632 Technical support to EU strategy on invasive species (IAS) - Assessment of the impacts of IAS in

633 Europe and the EU (final module report for the European Commission). Institute for European
634 Environmental Policy (IEEP), Brussels, Belgium. 44 pp.
635 Kijewski, T., Wijsman, J.W.M., Hummel, H., Wenne, R., 2009. Genetic composition of cultured and
636 wild mussels Mytilus from The Netherlands and transfers from Ireland and Great Britain.
637 Aquaculture 287, 292-296.
638 Kochmann, J., Buschbaum, C., Volkenborn, N., Reise, K., 2008. Shift from native mussels to alien
639 oysters: differential effects of ecosystem engineers. J. Exp. Mar. Biol. Ecol. 364, 1–10.
640 Lapègue, S., Boudry, P., Goulletquer, P., 2006. Pacific cupped oyster – *Crassostrea gigas*, in:
641 Crosetti, D., Lapègue, S., Olesen, I., Svaasand, T., (Eds), Genetic effects of domestication, culture
642 and breeding of fish and shellfish, and their impacts on wild populations. GENIMPACT project:
643 Evaluation of genetic impact of aquaculture activities on native populations. An European network.
644 WP1 workshop: Genetics of domestication, breeding and enhancement of performance of fish and
645 shellfish, Viterbo, Italy, 12.-17. June, 2006, 6 pp.
646 Lees, D., 2000. Viruses in bivalve shellfish. Int. J. Food Microbiol. 59, 81-116.
647 Lehane, L., 2000. Paralytic Shellfish Poisoning: A review. National Office of Animal and Plant Health,
648 Agriculture, Fisheries and Forestry. Canberra, Australia.
649 Lipp, E.K., Rose J.B., 1997. The role of seafood in foodborne diseases in the United States of
650 America. Revue Scientifique et Technique 16, 620-40.
651 McKindsey, C., Landry, T., O`Beirn, F., Davies, I.M., 2007. Bivalve aquaculture and exotic species: a
652 review of ecological considerations and management issues. J. Shellfish Res. 26(2), 281–294.
653 McMinn, A., Hallegraeff, G.M., Thomson, P., Jenkinson, A.V., Heijnis, H., 1997. Cyst and
654 radionucleotide evidence for the recent introduction of the toxic dinoflagellate *Gymnodinium*
655 *catenatum* into Tasmanian waters. Mar. Ecol. Prog. Ser. 161, 165-172.
656 Meyer, P.F., Mann, H., 1950. Beiträge zu Epidemiologie und Physiologie der parasitischen
657 Copepoden *Mytilicola intestinalis*. Archiv für Fischereiwissenschaften 2, 120-134.
658 Michaelis, H., 1978. Zur Morphologie und Ökologie von *Polydora ciliata* und *P. ligni* (Polychaeta,
659 Spionidae). Helgoland Wiss. Meer. 31, 102-116.
660 Minchin, D., 1996. Management of the introduction and transfer of marine molluscs. Aquatic
661 Conservation: Marine and Freshwater Ecosystems 6(4), 229–244.
662 Minchin, D., Duggan, C.B., Holmes, J.M.C., Neiland, S., 1993. Introductions of exotic species
663 associated with Pacific oyster transfers from France to Ireland. International Council for the
664 Exploration of the Sea, Copenhagen (ICES, Denmark). Mariculture Comm. Counc. Dublin, Ireland,
665 23. Sep.-1. Oct. 1993, 11, CM 1993/F:27.
666 Mons, M.N., Van Egmond, H., Speijers, G.J.A., 1998. Paralytic shellfish poisoning: A review. RIVM
667 Report 388802 005.
668 Mortensen S.H., 1993. Passage of infectious pancreatic necrosis virus (IPNV) through invertebrates in
669 an aquatic food chain. Dis. Aquat. Org. 16, 41–45.
670 Mortensen, S.H., 2000. Scallop introductions and transfers, from an animal health point of view.
671 Aquacult. Int. 8, 123-138.
672 Mortensen, S.H., Hjeltnes, B., Rødseth, O., Krogsrud, J., Christie, K.E., 1990. Infectious pancreatic
673 necrosis virus, serotype N1 isolated from Norwegian turbot (*Scopthalmus maximus*), halibut
674 (*Hippoglossus hippoglossus*) and scallops (*Pecten maximus*). Bull. Eur. Ass. Fish. Pathol. 10(2),
675 42–43.
676 Mortensen, S.H., Bachere, E., LeGall, G., Mialhe, E., 1992. Persistence of infectious pancreatic
677 necrosis virus (IPNV) in scallops (*Pecten maximus*). Dis. Aquat. Org. 12, 221–227.
678 Mortensen, S.H., Korsnes, K., Bergh, Ø., 2006. Eyes Wide Shut, a critical view of aquaculture health
679 management and risk factors in the “real world”. Bull. Eur. Ass. Fish. Pathol. 26(1), 2.
680 Odlaug, T.O., 1946. The effects of copepod *Mytilicola orientalis* upon the Olympia oyster *Ostrea lurida*.
681 Trans. Am. Microsc. Soc. 65, 311-317.
682 OIE, 2010. World Organization of animal health (OIE). Aquatic Animal Health Code., Renouf Pub Co
683 Ltd, 3rd edition, 301 pp.
684 O’Mahony, J.H.T., 1993. Phytoplankton species associated with imports of the Pacific oyster
685 *Crassostrea gigas*, from France to Ireland. International Council for the Exploration of the Sea,
686 Copenhagen (Denmark). Mariculture Committee. C.M. 1993/F:26. ref: K=L.

687 Perkins, F.O., 1976. Ultrastructure of sporulation in the European flat oyster pathogen, *Marteilia*
688 *refringes* – taxonomic implications. J. Protozool. 23, 64–74.
689 Read, P.A., Fernandes T.F., Miller K.L., 2001. The derivation of scientific guidelines for best
690 environmental practice for the monitoring and regulation of marine aquaculture in Europe. J. Appl.
691 Ichthyol. 17(4),146–152.
692 Reise, K., 1998. Pacific oysters invade mussel beds in the European Wadden Sea. Senckenbergiana
693 Marit. 28, 167–175.
694 RKI, 2000. Robert Koch Institute. Epidemiologisches Bulletin (ongoing), Berlin, Germany.
695 http://www.rki.de/DE/Content/Infekt/EpidBull/epid__bull__node.html, accessed January 2012.
696 SANCO/7221/2010. The Directorate-General for Health and Consumers of the European Commission
697 about the health status of farmed terrestrial and aquaculture animals (draft).
698 Salamina, G., D´Argenio, P., 1998. Shellfish consumption and awareness of risk of acquiring hepatitis
699 A among Neapolitan families - Italy, 1997. European Surveillance 3, 97-98.
700 Segarra, A., Pepin, J.-F., Arzul, I., Morga, B., Faury, N., Renault, T., 2010. Detection and description
701 of a particular Ostreid herpesvirus 1 genotype associated with massive mortality outbreaks of
702 Pacific oysters, *Crassostrea gigas*, in France in 2008. Virus Research, 153(1), 92-99
703 Shao, Z.J., 2001. Aquaculture pharmaceuticals and biologicals: current perspectives and future
704 possibilities. Adv. Drug Delivery Rev. 50, 229-243.
705 Smaal, A.C., Van Stralen, M.R., Craeymeersch J., 2005. Does the introduction of the Pacific oyster
706 *Crassostrea gigas* lead to species shifts in the Wadden Sea?, in: Dame R.F., Olenin S., (Eds.),
707 The Comparative Roles of Suspension-Feeders in Ecosystems, Springer, Berlin, Heidelberg, pp.
708 277–289.
709 Taskinen, J., 1998. Influence of trematode parasitism on the growth of a bivalve host in the field. Int. J.
710 Parasitol. 28, 599–602.
711 Thieltges, D.W., 2006. Effect of infection by the metacercarial trematodes *Renicola roscovita* on
712 growth in the intertidal blue mussel *Mytilus edulis*. Mar. Ecol. Prog. Ser. 319, 129-134.
713 Tiews, K., 1988. Die Miesmuschel in der Ökologie des Wattenmeeres. Inf. Fischwirtsch. 35, 110–112.
714 Tillmann, U., Rick, H.-J., 2003. North Sea phytoplankton: a review. Senckenbergiana Marit. 33, 1-69.
715 van Banning, P., 1990. The life cycle of the oyster pathogen *Bonamia ostreae* with a presumptive
716 phase in the ovarian tissue of the European flat oyster, *Ostrea edulis*. Aquaculture 84, 189–192.
717 Wachter, U., 1979. Parasiten und Kommensalen der Miesmuschel (*Mytilus edulis*) und die von
718 Trematoden induzierte Perlenbildung. Diplomarbeit, Universität Hohenheim, 50pp.
719 Wegeberg, A., Jensen, K., 1999. Reduced survivorship of Himasthla (Trematoda, Digenea) infected
720 cockles (*Cerastoderma edule*) exposed to oxygen depletion. J. Sea Res. 42, 325–331.
721 Wegeberg, A.M., Jensen, K., 2003. In situ growth of juvenile cockles, *Cerastoderma edule*,
722 experimentally infected with larval trematodes (*Himasthla interrupta*). J. Sea Res. 50, 37–43.
723 Wolff, W.J., Reise, K., 2002. Oyster imports as a vector for the introduction of alien species into
724 Northern and Western European coastal waters, in: Leppäkoski E., Gollasch S., Olenin S., (Eds),
725 Invasive aquatic species of Europe: distribution, impacts and management, Kluwer Academic
726 Publishers, Dordrecht, pp. 193–205.
727