Ministry for Primary Industries
Manatū Ahu Matua

LITERATURE REVIEW OF ECOLOGICAL EFFECTS OF AQUACULTURE

Effects from Additives

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10.1 Introduction

Currently, there is minimal use of chemicals such as antibiotics, antibacterials and other therapeutants in the New Zealand aquaculture industry; however, culture of native species may lead to the emergence of diseases that may require new treatments. In relation to the farming of feed-added species, zinc is added to fish feed, and copper is used as an antifouling agent on structures. No chemical/additives are known to be used in the farming of bivalves and lower trophic level species.

The need to use chemicals in aquaculture varies depending on the species farmed and the scale and intensity of farming. Chemicals are used for the maintenance and sustainability of farming activities, and inputs into the marine environment from aquaculture activities generally fall into two categories: intentional and unintentional inputs.

Intentional inputs include metals coming from antifoulants (copper, zinc), therapeutants to treat animals from bacterial diseases or parasites (antibiotics and parasiticides), anaesthetics and detergents/disinfectants to prevent the spread of diseases. Unintentional inputs include chemicals from fish feed additives (zinc), drug formulations and plastic debris.

The use of chemicals in New Zealand aquaculture is controlled and monitored to minimise environmental effects. All species cultured for human consumption have to meet strict food safety standards, which regulate the acceptable concentrations of metals, chemicals and additives in food products. New Zealand salmon farmers must also comply with the New Zealand Salmon Farmers Association's Finfish Aquaculture Environmental Code of Practice, with harvesting and processing in accordance with New Zealand food safety standards.

Aquaculture is still a growing industry in New Zealand, and background data on the use and impact of chemicals locally are very limited. Most of the information on their use in aquaculture comes from research on salmon aquaculture and has been reviewed previously (Forrest et al. 2007a, 2007b; Wilson et al. 2009; Burridge et al. 2010; Clement et al. 2010; Forrest et al. 2011).

10.1.1 Overview of chemical effects

Metals

Metals, like copper and zinc, are found in anti foulant paints and feed additives, respectively. They are naturally present in the water column at trace level concentrations (about 0.5µg/L and 2µg/L respectively) that vary depending on location (Drever 1982). Organisms require these essential elements for physiological processes and growth. As such, they are considered normal constituents in the ecosystem in both soil and water. They cannot be degraded and can accumulate and persist in sediments. The amount of copper and zinc required for normal metabolism is small and, for this reason, they are considered micronutrients. However, they can be detrimental to organisms if concentrations exceed those required by the organism.

Copper and zinc are components of many enzymes and proteins that are important for metabolism. If levels greatly exceed an organism's normal requirements, these particular trace metals begin to interfere with and/or compete for enzymes or membrane protein sites. If regulation processes start to break down, this can lead to a greater influx of metals that can no longer be removed and are, instead, accumulated within the organism. As metals internally accumulate past an organism's threshold, they become increasingly toxic to the animal itself. Previous reviews (Forrest et al. 2007b; Clement et al. 2010; Forrest et al. 2010) provide an additional overview of the ecological impacts of copper and zinc in relation to aquaculture in New Zealand.

Therapeutants

As a result of aquaculture activities, therapeutants (antibiotics and parasiticides) used against bacterial diseases and parasites are released into the marine environment where they can be stable and accumulate in the sediment. However, due to the low use of therapeutants in New Zealand, little is known on their fate in the New Zealand marine environment. Most of the available data on therapeutants come from countries having more extensive activities. The main concern with these compounds is their potential to affect non-target organisms (phytoplankton and zooplankton, sediment bacteria) and the rise of resistant bacteria and/or parasites (GESAMP 1997; Forrest et al. 2007a, 2007b; Forrest et al. 2011).

Anaesthetics are used operationally in aquaculture when fish are harvested or sorted. The main active substance from the only fish anaesthetic licensed for use and used in salmon aquaculture in New Zealand eugenol, is of little risk to the environment.

Detergents and disinfectants

Detergents and disinfectants are currently not regulated. Thus, in areas around wharves or in small sheltered coves, inputs could be significant. Some degrade rapidly in the environment, while others may persist and affect organisms in the surrounding area. The effects can range from impacts on microalgae to fish behavioural disruption (GESAMP 1997; Ivankovic & Hrenovic 2010; Liu et al. 2011).

Plastic debris

Farming equipment can produce plastic debris that can have a long-term impact depending on the type of plastic used. Specifically, ingestion of plastic debris by marine animals can cause toxicity due to the potential release of plasticisers in the organism. These plasticisers are known to have endocrine disrupting effects (the mechanical effects of plastic debris are described in Chapter 4 – Effects on Marine Mammals.

10.2 Feed-added species (salmon, kingfish, hapuku)

10.2.1 Descriptions of main effects and their significance

10.2.1.1 Effects associated with metals (copper and zinc)

Table 10.1: Effects associated with metals (copper and zinc) from feed-added aquaculture operations.

Description of effect(s)	Increased metal concentrations above a threshold cause a breakdown in an organism's internal metal regulation or accumulation, leading to sub-lethal or acute (mortality) toxicity effects. The variability in acute and/or chronic toxicity effects in both pelagic and benthic organisms ranging from phytoplankton, zooplankton, crustaceans, molluscs, echinoderms, annelids and fish, is high. High concentrations of metals in organisms can inhibit growth and settlement of larvae, interfere with respiration, metabolism, reproduction and/or provoke abnormal behaviours. Effects on communities can lead to the absence (due to avoidance or mortality) of intolerant species and/or to the temporary increase in abundance of more tolerant species. Extreme metal concentrations generally lead to reduced diversity and composition of benthic fauna. Toxicity on microbiota can affect benthic functions through altered geochemical processes that regulate the cycling, bioavailability and fate of micronutrients and macronutrients. Copper and zinc contribute to the selection of multi-resistant bacteria. Effects of copper can be enhanced by zinc (synergistic interaction).
Spatial scale	*Local scale*. More likely to follow the depositional pattern of organic matter discharges from farms, but remains persistent in sediments. Concentrations fall to background levels between 50 to 150 metres from farm centre.
Duration	*Medium term*; accumulated metals in sediments can be resuspended via biological activities (bioturbation) or extreme/exceptional events.
Management options	Off-site washing to prevent particles reaching the seabed. Fallowing and rotational use of available farm sites. Continuous monitoring of a fallowing farm provides information on the rate and extent to which sediment conditions and benthic communities can recover. Use of a framework plan to minimise monitoring effort where it can be demonstrated that sediments beneath farms are maintained below a metal threshold.

Table 10.1: Effects associated with metals (continued)

Knowledge gaps	Mechanisms of metal level fluctuations in sediments (spatial variability, recovery processes, dispersal or removals, trophic transfers and accumulation processes). Partition of metals in sediment between solid and pore-water with toxicity implications. Sediment recovery processes affected by increased metal levels (including microbial ecology). Significance of the uptake, bioaccumulation or toxicity in organisms that reside or spend part of their reproductive cycle in the water column.

* Italicised text in this table is defined in chapter 1 – Introduction.

Summary

Copper is the most commonly used compound to control biofouling in the marine environment. The principal way it enters the environment is by leaching from antifouling paint or being deposited with paint flakes during mechanical defouling of farm structures. Finfish nets are treated by immersion in land-based tanks of antifouling paint, and these nets may leach compounds into the surrounding water. Ablative antifouling paints (including copper-based formulations) slough off over time and can accumulate in sediments beneath finfish farms.

The quantity of copper (in the form of cuprous oxide, Cu_2O) in the paint is usually specified by manufacturers as a range but puts annual copper usage in the range of 230 to 700 kilograms per farm. Most of this copper remains on the net until it is cleaned onshore prior to recoating. Preliminary tests on biofouled nets by the Tasmanian Salmonid Growers Association Ltd (TSGA) determined that 21 percent of the copper agent from the original coating of a net entered the marine environment (Clement et al. 2010). This proportion, however, would be highly specific to each operation, dependent on factors such as cycling time, water flow and interim cleaning practices.

In the Marlborough Sounds, individual salmon farms use approximately 500 to 1500 litres of antifoulant paint per year. The cleaning protocol for salmon farms within the Marlborough Sounds is to partially water-blast nets while still in the water and/or remove any larger fouling organisms (such as mussels) as the net is pulled from the water and fed through a type of wringer. Removed nets are fully cleaned once on shore, where they are re-coated and allowed to dry (Clement et al. 2010).

Recent (2005 to 2010) assessments at salmon farming sites in this area revealed locally elevated copper levels (with a maximum of approximately 900 mg/kg) exceeding Australian and New Zealand Environment Conservation Council (ANZECC) sediment quality guideline values (ANZECC 2000, Appendix 8.1) (Hopkins et al. 2006).

Free copper ions (Cu^{2+}) are considered the most toxic while complex forms are considered the least toxic to aquatic organisms. Copper in solution may be passively or actively taken up by pelagic organisms. Phytoplankton is immediately susceptible to dissolved copper and considered to be highly sensitive. The effects of heavy metals on phytoplankton are especially relevant since these organisms constitute the base of the marine food web. Heavy metals exert their toxic effects by competing with essential metals for active enzyme or membrane protein sites and by reacting with biologically active groups. Thus, these metals may interrupt the normal metabolic processes of algal cells. Different phytoplankton species exhibit different sensitivities to copper (MacLeod & Eriksen 2009). When exposed to elevated levels of waterborne copper, fish accumulate the metal residues primarily in the liver and also in the gills (MacLeod & Eriksen 2009). Copper exposure can exert a variety of physiological effects in fish. In developing fish larvae, copper can affect key parameters such as survival and growth (Johnson et al. 2007). Chronic effects include reduced growth, shorter lifespan, reproductive problems, reduced fertility, reduced resistance to infectious disease and behavioural changes (Atchison et al. 1987; Nowak & Duda 1996). As copper is not degraded and can remain in the sediment, recovery mainly involves fallowing (Brooks & Mahnken 2003).

Zinc primarily comes from feed (uneaten and released in faecal wastes) but also from antifouling paints depending on the formulation. Standard feed for salmon and kingfish in New Zealand contains zinc (concentrations of approximately 100 mg/kg of feed), which is an essential micronutrient for the prevention of cataract formation and other health problems. When not fully absorbed by the organism, it is discharged in faecal matter (Clement et al. 2010). Zinc can accumulate in sediments beneath fish farms and be toxic at high concentrations. It has been found at environmentally significant levels beneath salmon farms in New Zealand (Morrisey et al. 2000) and overseas (Solberg et al. 2002; Brooks & Mahnken

2003). In the Marlborough Sounds, recent assessments at salmon farming sites in this area (between 2005 and 2010) showed locally elevated zinc concentrations (with a maximum found at 1700 mg/kg) exceeding sediment quality guideline values set out in Appendix 8.1 of ANZEEC (2000). In this area, the natural background concentration of zinc in sediments ranges from 42–69 mg/kg (Hopkins et al. 2006).

Potential adverse effects from high zinc exposures range from interference with growth or reproduction, osmoregulatory failure, pancreatic, gill or immunity damage and/or behavioural abnormalities (Eisler 1993; Burridge et al. 2010).

Elevated metal concentrations do not necessarily indicate adverse ecological effects (Forrest et al. 2007b) because the bioavailability of metals is likely to be limited by high sediment sulphide levels that occur under anaerobic conditions. This results in the formation of metal sulphide, which is largely insoluble and therefore not available for biological uptake. Nonetheless, high concentrations may hinder long-term faunal recolonisation rates, for example, if a site is fallowed (Morrisey et al. 2000).

It is important to note that most of the information on metal toxicity effects was obtained experimentally and often involved adding soluble copper or zinc to clean seawater (e.g., no complexing agents). Therefore, higher concentrations of free metal ions were biologically available to test organisms than would naturally occur around a farm site.

10.2.1.2 Effects associated with therapeutants (antibiotics and parasiticides)

Table 10.2: Effects associated with antibiotics from feed-added aquaculture operations.

Description of effect(s)	Chronic use can increase the potential of bacterial resistance. It can affect plankton composition and impacts on nitrogen processing bacteria.
Spatial scale	*Local scale*. Predicted to follow the depositional pattern of organic matter discharges from farms.
Duration	*Short term*. These compounds can be degraded either biologically or chemically.
Management options	Husbandry, antibiotic delivery improvements and vaccine use. Antibiotics use is regulated by the Agricultural Compounds and Veterinary Medicines Act (ACVM 1997). Monitoring the volume of antibiotic use by a regulatory body dealing with aquaculture and fish health through monitoring of veterinary prescriptions originating from aquaculture sites. Reporting the incidence of disease, the products prescribed for treatment and quantities used.
Knowledge gaps	• Data on use of therapeutants. • Distribution of therapeutants after use. • Level of impact on non-target species. • Effects of changing environmental conditions on chemical status degradation and toxicity. • Identification of factors influencing resistance. • Effects on sediments and ecological processes. • Interactions with other compounds.

* Italicised text in this table is defined in chapter 1 – Introduction.

Table 10.3: Effects associated with parasiticides from feed-added aquaculture operations.

Description of effect(s)	In the long-term, parasites can develop resistance to parasiticides. Non-target organisms can also be affected.
Spatial scale	*Local scale*. They can be either dispersed in the water (some compounds can be detected as far as 3000 metres but only for a short time) or bind to organic matter and be found in sediment.
Duration	*Very short term*. They can be easily diluted and then degraded.
Management options	Decreasing the spread of diseases and, consequently, the use of parasiticides by having cage separation requirements.
Knowledge gaps	• No apparent data regarding the effects of these chemicals on micro-organisms and planktonic species forming the foundation of the marine food chain in the near-shore environment. • Ecotoxicity data on sub-lethal effects over longer time scales are needed. • Thresholds of effects based on chronic endpoints for indigenous species.

* Italicised text in this table is defined in chapter 1 – Introduction.

Summary

Therapeutant treatments are typically parasite or disease specific. As such, the potential for environmental issues from therapeutant use will need to be assessed on a case-by-case basis. At present in New Zealand, the salmon aquaculture industry has occasionally used oxytetracycline for the treatment of vibriosis although this has become rare with improvements in fish husbandry. With the expansion of finfish aquaculture into new species and the expansion of industry into new areas or larger regions, such chemicals are likely to become necessary again. For example, kingfish (*Seriola* spp.) and hapuku are under development as new aquaculture species. Early indications suggest that there will be a need for some disease treatments because kingfish appear to be susceptible to infection by monogenean parasites and hapuku may be affected by ciliates.

Most parasiticides have limited environmental ramifications as they are usually highly water soluble, break down readily and do not bind to sediments (e.g., formaldehyde (WHO 2002)). However, some are administered as feed additives and, therefore can be deposited on to the seabed.

Despite their low toxicity, there are significant environmental concerns with widespread use of antibiotics. They are generally administered in feed and, as such, the main concerns relate to the presence of waste feed and fish excretory material in the sediments and water column.

Many antibiotics are stable chemical compounds that are not broken down in the body but remain active long after being excreted in faeces and urine and after passing to the environment with uningested food falling through the cages and accumulating on the sea bed (Jacobsen & Berglind 1998; Burridge et al. 2010). Antibiotics may be found in the water and in the sediments and can affect aquatic organisms in a number of ways (Hansen & Lunestad 1992; Halling-Sorensen et al. 1998). For example, aquatic ecosystems are largely controlled by, and are dependent on, microbial organisms for a suite of crucial processes (e.g., denitrification), associations (e.g., nitrogen fixation) and services (e.g., organic breakdown). Accumulation of antibiotics in sediments may interfere with bacterial communities and affect the rate and mechanism for mineralisation of organic wastes (GESAMP 1997; Costanzo et al. 2005). Plankton community composition can be affected by antibiotics, with toxicity varying widely depending on application rates and natural factors (Isidori et al. 2005; Christensen et al. 2006). Current data indicate that water column concentrations of antibiotics are extremely low and that impacts on phytoplankton communities are likely to be limited. Algae can also be relatively sensitive to antibiotics (Isidori et al. 2005). These data are derived from laboratory-based culture experiments and, as such, are based on concentrations that would be rarely, if ever, encountered in the broader environment in association with aquaculture.

Given the dilution that occurs with antibiotic usage in cage aquaculture in the coastal environment, such concentrations would be very unlikely. However, several studies have shown an increase of antibiotic, resistant bacteria in the sediments beneath cages (GESAMP 1997; Miranda & Zemelman 2001). It is therefore important to monitor the incidence of resistance in the environment and in fish bacteria. Accumulation in the sediments may also affect natural sedimentary processes, such as biogeochemistry (Costanzo et al. 2005).

The most important means to reduce and manage overall antibiotic usage would be to facilitate diagnosis of pathogens and to support development of targeted disease management strategies and alternative therapies, in particular, vaccines. Vaccines are available for most bacterial fish pathogens, but none are presently licensed for use nor used in New Zealand.

At present, parasiticides are not used in sea-cage aquaculture of Chinook salmon. The introduction of new indigenous species for aquaculture may see the development of novel disease situations, which could include use of treatments for ciliates, monogenean parasites or *Caligus* species of sea lice. Animals can be treated by a variety of bath treatments including, but not limited to, hydrogen peroxide, formalin, praziquantel (Rodgers & Furones 2009).

Laboratory-based studies showed that some organisms, like arthropods, can be particularly sensitive to these compounds whereas molluscs, echinoderms and fish tend to be less sensitive. Parasiticides may also contribute to the selection of resistant parasites. Some parasiticides can be regulated if they pose potential threat to human health and the environment (ACVM 1997).

10.2.1.3 Effects associated with detergents and disinfectants

Table10.4: Effects associated with detergents and disinfectants from feed-added aquaculture operations.

Description of effect(s)	Slightly toxic to surrounding organisms, some compounds can have potential endocrine disrupting effects, also disrupting enzymatic activities; they can damage proteins, nucleotides, and fatty acids, leading to the death of cells, but not whole organisms. Some studies show a reduction of filtering activities in surrounding bivalves.
Spatial scale	*Local scale*. These compounds are used in equipment preparation to maintain hygiene throughout the production cycle and, in some cases, to treat diseases.
Duration	*Very short term*, depending on the solubility and degradation in the environment.
Management options	Use of low toxicity impact compounds and off-site cleaning can reduce impact.
Knowledge gaps	Very few data are available regarding the presence of disinfectants, particularly of formulation products, in the marine environment. Studies need to be conducted to document the patterns of use and the temporal and spatial scales over which compounds can be found.

* Italicised text in this table is defined in chapter 1 – Introduction.

Summary

Detergents (or surfactants) are complex mixtures containing a variety of ingredients, particularly surface-active agents (surfactants), builders, bleaches and additives, blended for specific performance characteristics (Hennes-Morgan & de Oude 1994). All of the compounds used are water soluble and should be of low toxicity depending on quantities used. Risk of aquatic biota being exposed to the disinfectant formulations is dependent not only on how much is being used but where it is being released.

10.2.1.4 Effects associated with plastic debris

Table 10.5: Effects of endocrine-disrupting compounds associated with plastic debris from feed-added, filter-feeder or lower trophic level aquaculture operations.

Description of effect(s)	Endocrine-disrupting compounds in plastics affect hormone production and distribution; long exposure to these compounds can affect basic life functions, such as development of the reproductive system, growth, maintenance of the body's internal environment, and production, use and storage of energy (Zhou et al. 2009).
Spatial scale	*Regional to international*; debris can be carried over long distances.
Duration	*Very long term* as it is related to the degradation rate of the plastic.
Management options	Use of good practice and environmentally friendly plastic.
Knowledge gaps	Effective concentration of plasticisers leaching from debris and response of organisms. Plastics are made of a mixture of plasticisers that can interact with each other in the organism and with other chemicals ingested from other sources. Research on the types of interactions on marine organisms and their long-term effects needs to be carried out.

* Italicised text in this table is defined in chapter 1 – Introduction.

Summary

Plastic can be released from normal work handling or after extreme events (storms). Some sink immediately to the sea floor while others might remain afloat for extended periods (weeks to several months). To minimise the impact, non-biodegradable material lost or removed from the structures (anchors, lines, droppers, ties, buoys, cages and timber), should be removed as soon as practicable from the seabed, water column or foreshore and disposed of on land.

Operational by-products of farms released in the environment are often made from plastic that can become easily broken down into smaller fragments in the environment. Many of the plastics contain considerable quantities of polychlorinated biphenyls as plasticisers (such as bisphenol A, phthalates). These plasticiser materials may be lost into the surrounding seawater during weathering and small pieces might be incorporated into marine algae and animals (Leichert 2001). Once ingested, these compounds can leach out in the organism and have endocrine disruption effects.

More environmentally friendly plastics are available now. They use fewer chemicals that could have impacts and are more easily biodegradable. Plastics represent a large mixture of molecules that can be released in the environment. The individual effects of different molecules have been well studied; however, research to understand their interaction and the long-term effects (over several generations) remains limited. It is difficult, once plastics are released in the environment, to determine what comes from aquaculture and what come from other pollution.

10.2.2 Factors relating to all chemical effects

10.2.2.1 Farm attributes

The chemicals entering the environment will obviously depend upon what chemicals are used during the operation of an aquaculture site. Inputs can be intentional or unintentional. Intentional inputs come from treatment of fish for bacterial infection and infestations of parasites. In addition, antifouling compounds are applied to nets and disinfectants are routinely used to enhance biosecurity at aquaculture sites. Unintentional inputs include constituents of food, litter, fuel and oil from boat traffic.

10.2.2.2 Physical site attributes

Toxicity of chemicals is strongly influenced by the properties of water and sediments. The hydrology of sites can affect the concentration of chemicals. For example, high flow sites have higher dilution rates than low flow sites. In seawater, the bond of chemicals to solids and organic matter is less important than in freshwater due to the high concentration of competing ions. Sediments can trap metals and organic compounds. In water with high dissolved organic content, metals can become bound in soluble and insoluble complexes, which reduce their bioavailability. Svobodova et al. (1993) note that compounds that are slow to dissolve or are insoluble are unlikely to be taken up to any extent into body tissue, so their toxicity to fish is low.

10.2.3 Impact mitigation and management strategies

Farms are located in waters with different capacities to absorb wastes, including chemicals, without causing unacceptable environmental impacts. Risks therefore have site-specific components (hydrology, chemical characteristics), and management of these risks may therefore require site-specific assessments of the quantities of chemicals that can safely be used at each site.

The New Zealand fish farming industry and feed supply companies implement various measures to minimise contaminant inputs to the environment, which is likely to lead to reduced contaminant loads in the future. The use of copper antifoulant paints is minimised to structures where it is essential ,,and manual defouling is used on other structures. Feed companies are presently investigating ways of reducing levels of nutritional therapeutants (e.g., zinc) in feed and, consequently, minimising discharges to the seabed, primarily by reducing the content in the feed and by replacing fish products with alternatives. This includes sourcing raw fish products from regions where contaminants are relatively low.

Feed wastage can be minimised by monitoring feed input and therefore limiting feed wastage. Minimising the impact of therapeutants can be achieved by avoidance of disease, controls on therapeutic use, use of hygienic measures in fish rearing and vaccination (Burridge et al. 2010). Fallowing could be a solution for remediation of impacted sites. Brooks et al. (2003, 2004) observed that the complete remediation of an impacted farm site occurs on a variable time scale from several months to several years, depending on the level of impact and recovery conditions such as water currents, dissolved oxygen in the water column and the availability of opportunistic, tolerant species to colonise the affected area.

Spacing farms further apart from one another may reduce accumulation of metals in one area and prevent spreading of diseases and, therefore, result in a reduction of the use of therapeutants. Antibiotics usage has been reduced significantly in Canada and Norway in the past decades with the implementation of targeted management strategies, including development of vaccines and husbandry practices such as early diagnosis of problems and maintaining optimum conditions for parameters such as feed rates, water dissolved oxygen, stocking densities (Rodgers & Furones 2009).

With the further development of the finfish farming industry in New Zealand, it is important that similar mitigation measures are encouraged as part of “best management practice”.

The same approach to minimising ecological effects associated with biodeposition on the seabed (see Chapter 3 – Benthic Effects) can also be adopted to reduce the effects of pollutants. This approach is, in part, based on zones of impact defined for salmon farming off the Scottish coast (allowable zone of effects (AZE)) (SEPA 2000). The approach specifies the spatial extent over which defined levels of seabed impact are permitted. Another zone concept (or neighbourhood or district concept) is being implemented in Chile introducing independent farm management areas (Barton & Fløysand 2010). These areas have regulatory controls imposed for disease mitigation. These controls impose co-ordinated production and sanitary measures within a district and restricts movement of fish and equipment between districts.

The US Food and Drug Administration has required a basic assessment of all new drugs as part of the licensing process, however, the process was reviewed in 1995 and the latest environmental assessment requirements were published in 1998.

The most important means to reduce and manage the overall antibiotic usage would be to facilitate diagnosis of pathogens and to support development of targeted disease management strategies and alternative therapies, in particular, vaccines. Vaccines are available for most bacterial fish pathogens but none are presently licensed for use, nor used, in New Zealand.

10.2.3.1 Environmental quality standards

Metals

ANZECC has derived low and high interim sediment quality guidelines (ISQG-Low and ISQG-High) (ANZECC 2000) for each trace element and organic compound to benchmark sediment monitoring data. ANZECC recommends that sediment concentrations of copper and zinc continue to be the focus of environmental monitoring because they are the principal indicators of environmental accumulation of metals. The available information does not suggest that a standard greater than the ANZECC ISQG-Low criteria is appropriate for sediments beneath farms, based on either ecotoxicological data or long-term limitations in bioavailability. As such, ISQG-Low should be used as the first-tier trigger level for further actions.

An Environmental Monitoring Adaptive Management Plan (EM-AMP) has been proposed to minimise monitoring effort where it can be demonstrated that sediments beneath farms are maintained below trigger levels for metals (Keeley 2012). Upon exceeding trigger levels, monitoring effort would intensify progressively to maximise the collection of useful data and remove uncertainty. Where it becomes clear that sediment trigger levels are exceeded by the metal of concern, in its bioavailable form, management action would be precipitated to curb inputs to the system and/or research would be instigated to examine the actual bioavailability and toxicity of the contamination and potentially replace the trigger levels in the EM-AMP with site-specific criteria.

The Scottish Environmental Protection Agency (SEPA) acknowledges the need for a mixing zone around cage fish farms, where pollutants can be first diluted and specifies that the water and seabed are changed from their normal state only within an AZE (SEPA 2000). An AZE allows the relevant environmental quality standard to be exceeded and also allows some damage to the environment within that zone. Trigger values for metals in sediments are outlined in various government agency guidelines (ANZECC, National Oceanic and Atmospheric Administration (NOAA), Florida Department of Environmental Protection (FDEP), SEPA). These guidelines provide recommended values within impacted zones in sediments up to 270 mg/kg for copper and 410 mg/kg dw for zinc, and in water up to 4.8 *μ*g/L for copper and 15 *μ*g/L for zinc (ANZECC 2000). (See Appendices 10.1 and 10.2.)

Therapeutants (antibiotics and parasiticides)
In New Zealand, use of therapeutants in animals is controlled by the ACVM Act 1997. If therapeutants (anti-parasites and so on) pose a threat to human health and to the environment they should be assessed for public health and environmental risks (Hazardous Substances and New Organisms (HSNO) Act 1996).

Antibiotics are also regulated and require consent for their use. Oxytetracycline is the only antibiotic listed for fish (with a maximum residue limit of 0.2 mg/kg) (FSANZ 2008). The latest Australia and New Zealand water quality guidelines have tried to adopt a risk-based approach, although not a full quantitative risk assessment. They propose using the criteria outlined in the previous ANZECC guidelines as indicative trigger values, to assist in a decision framework for local, regional or site-specific environmental conditions. The guidelines include a provision to protect environmental water quality for the purpose of ecosystem sustainability, both in general terms and in relation to aquaculture species specifically. They also include specific guidelines on water quality criteria for human health. However, antibiotics are not amongst the listed chemicals of concern in either document. References to criteria for assessment of bioaccumulation and ecotoxicity effects are restricted to those affecting aquaculture species. Consequently, the only currently available standards are those that relate to human health and food safety (FSANZ 2008).

In the largest fish farming countries, the use of antibiotics is monitored and reporting of the use and quantity applied is required. In Norway, only six antibiotics which are not considered relevant for human medicine can be used in aquaculture. In Scotland, antibiotic usage on fish farms comes under the SEPA regulations as “intermittent discharges”. The favoured approach for control of these medicines is to model dispersion over a three-hour period, use this output to identify the AZE and then compare the calculated predicted environmental concentration with the relevant environmental quality standard (EQS); unfortunately, there are no available EQS for antibiotics. Discharge is also regulated; a medicine or chemical agent cannot be discharged from a fish farm installation unless formal consent under the Control of Pollution Act 1974 has been granted to the farm concerned by SEPA.

Detergent and disinfectants
There are few environmental standards for detergent and disinfectants. Aquaculturists are required to ensure that the potential for contamination of the environment will be minimised when using disinfecting agents and the use of environmentally friendly detergents (without nonylphenol ethoxylate, phosphates, or with new chemicals that are easily biodegradable) is recommended.

Plastic debris
To minimise the impact, non-biodegradable material lost or removed from structures (anchors, lines, droppers, ties, buoys, cages and, timber), should be retrieved as soon as practicable from the seabed, water column or foreshore and disposed of on land.

10.2.4 Knowledge gaps

Metals
Most research, and all regulations, pertaining to metal release from aquaculture operations is focused on near-field concentrations. Studies on the bioavailability and forms of the metals will give a better understanding of their toxicity; a focus is needed on sub-lethal effects on individual species and broader effects on benthic communities. Currently, there is limited research on the fate of metals and re-suspension of near-field sediments. The question of where metals are transported and what effect this may have in the far-field environment has not been addressed.

Therapeutants (antibiotics and parasiticides)
Use of therapeutants in New Zealand is low, and impacts on local ecosystems are difficult to assess. But their persistence

in the environment, the induction of resistance of targeted organisms and the effects on non-target organisms remain the main knowledge gaps. Accumulation in the sediments may affect natural sedimentary processes, such as biogeochemistry, and it would be prudent to confirm this and to determine threshold effect levels. This could be done either in mesocosm experiments with field validation through targeted assessments or in conjunction with measurements of biotic loading and resistance. Also, new indigenous species for aquaculture have their own native parasites and diseases, leading to novel fish health issues requiring different treatments and representing a potential knowledge gap.

Detergents and disinfectants

There is limited data available regarding the presence of disinfectants and, particularly, of formulation products in the marine environment. Studies need to be conducted to document the patterns of use and the temporal and spatial scales over which compounds can be found.

Plastic debris

There is very little data available on the impact of chemicals leaching from ingested plastic debris. Volume, chemical characteristics and the fate in the environment of plastic debris are hard to determine and should be studied to assess their chemical impact on organisms.

10.3 Filter feeders (Green-lipped mussels and Pacific oysters)

10.3.1 Overview of chemicals effects

Shellfish farm operations do not require the ongoing use of chemicals that can introduce contaminants to the marine environment. However, wooden racks are constructed from treated timber and therefore have the potential to leach trace contaminants such as copper, chromium and arsenic (CCA). This type of timber could also be used for lower trophic level farming, such as sea cucumbers, for pen construction (Section 10.4) but does not seem to be used for fish farming.

Copper and chromium are essential elements required for normal growth in organisms. As such, they are considered normal constituents in the ecosystem in both soil and water. The amount of copper and chromium required for normal metabolism is small and, for this reason, these metals are considered micronutrients. However, they can be detrimental to organisms if concentrations exceed those required by the organism. They can interfere with cell metabolism at toxic levels, leading to various physiological disruptions. Arsenic is a metalloid not necessary to life and can cause deleterious effects to an organism.

The use of antibiotics is rare for filter feeders, but their potential impacts on other aquatic organisms and their habitat cannot be disregarded. Concerns around their use are mainly with the potential of these compounds to affect non-target organisms (phytoplankton and zooplankton, sediment bacteria) and the rise of resistant bacteria. But, as for finfish, due to the low use of antibiotics (or none) in New Zealand, described effects come from studies in countries with more extensive farming.

Farming equipment can produce plastics debris that can have a long-term impact, depending on the type of plastic. When ingested, some plastics can leach chemicals into the organism. These mechanical effects of plastic debris are described in Chapter 4 – Effects on marine mammals.

10.3.2 Descriptions of main effects and their significance

10.3.2.1 Copper, chromium and arsenic treated timber

Table 10.6: Effects associated with Copper, chromium and arsenic treated timber in filter-feeding or lower trophic level aquaculture operations.

Description of effect(s)	Most of the effects relate to individuals contaminant toxicity and potentially their interactions. Copper can accumulate and persist in sediments and organisms when introduced at concentrations higher than natural background. Its effects can be observed on reef communities in the vicinity of farms either from direct (water column) or indirect (e.g., food web) mechanisms. Copper can accumulate in organism and elevated concentrations of copper can quickly interrupt the normal cell metabolic processes, causing growth rate reductions, loss of osmoregulatory functions, weight and biomass loss, dysfunctional sensory responses, shortened lifespan and/or reduced resistance to infectious diseases. Copper also contributes to the selection of multi-resistant bacteria. Chromium can trigger reductions of algal growth, and inhibition of polychaete worms can be observed at low chromium concentrations (around 10μg/l). At higher concentrations, chromium (VI) is associated with abnormal enzyme activities, altered blood chemistry, lowered resistance to pathogenic organisms, behavioural modifications, disrupted feeding, histopathology, osmoregulatory upset, alterations in population structure and species diversity indices. Arsenic can cause direct inhibition of cellular respiration, have mutagenic effects and cause hemolysis and chronic stress in several marine organisms.
Spatial scale	*Local scale*. CCA leaching is rapidly diluted in water, only the sediment around the pile is likely to accumulate contaminants.
Duration	*Short term*. Contaminant release from treated timber in seawater is reported to decrease exponentially over time.
Management options	When used in moderately well circulated bodies of water; the levels of copper resulting from the use of properly treated CCA wood products are normally well below regulatory standards and will produce concentrations far below those causing acute or chronic stress in even the most sensitive taxa. The use of alternative construction materials or the development of strict regulatory guidelines around the use of treated timber for farm structures is also an option.
Knowledge gaps	Accumulation and interactions of pollutants. Long-term effects of sub-lethal concentrations on higher complexity organisms are unknown.

* Italicised text in this table is defined in chapter 1 – Introduction.

Summary

Wooden racks are constructed from treated timber and hence they have the potential to leach trace contaminants such as CCA. These contaminants are likely to bind to sediments after their release and be deposited locally, with overseas studies describing elevated concentrations in seabed sediments immediately adjacent to treated piles (Weis et al. 1993). However, the release of contaminants from treated timber in seawater is reported to decrease over time (Brooks 1997), and sediment binding is likely to reduce the potential for accumulation in oysters or toxic effects on sediment-dwelling biota. Nonetheless, in the apparent absence of any information that describes this issue in relation to oyster farming, contaminant accumulation and associated toxicity cannot be discounted (Forrest et al. 2007a).

The toxicity of treated timber is related to which chemicals are used to treat it. Copper is more toxic than arsenic or chromium in marine environments. At concentrations slightly above those required as a micronutrient, copper can be toxic, especially to the very sensitive larval (gametes and embryos) stages of marine invertebrates (Harrison et al. 1987).

Chromium toxicity to aquatics species can vary by an order of magnitude, or more, depending on a variety of biological and physical factors. Chromium can accumulate in organisms, (fish, invertebrates) tissues more likely through the food chain

(Oana 2006). Chromium (VI) is the most biologically active form (compared to chromium (III)) as it can be transported into the cells. Naturally occurring ligands and sequestering agents in seawater may alleviate the toxicity of chromium VI and other metals.

Arsenic is a common environmental metalloid whose toxic properties have been known for centuries. The toxicology of arsenic may be divided into three general areas: direct inhibition of cellular respiration, mutagenic effects and hemolysis. It can cause chronic stress for the most sensitive algae and animals at concentrations as low as 19µg/L and 230µg/L, respectively (Brooks 1997).

We note that farmed shellfish are subjected to metals testing as part of water quality programmes, which would presumably detect biologically relevant accumulation should it occur. Nonetheless, there is an increasing trend overseas to use alternative construction materials, or to develop strict regulatory guidelines around the use of treated timber for oyster farm structures (e.g., DPI 2008); (Keeley et al. 2009).

It would be relatively straightforward and inexpensive to collect and analyse sediment samples from beneath racks, and compare contaminant concentrations to ANZECC (2000) guidelines to ascertain whether this is an issue that warrants more thorough investigation.

10.3.2.2 Antibiotics

Table 10.7: Effects associated with antibiotics from filter-feeder or lower trophic level aquaculture operations.

Description of effect(s)	High dosage and long-time use can increase the potential of bacterial resistance. It can affect plankton composition and impacts on nitrogen-processing bacteria.
Spatial scale	*Local scale.* These will follow the depositional pattern of organic matter discharges from farms.
Duration	*Short term.*
Management options	Land-based hatcheries can use diversion or decontamination techniques to prevent compounds from entering the marine environment. Reporting of quantity applied. Husbandry and antibiotic delivery improvements.
Knowledge gaps	• Levels of (un)acceptable impact on non-target species. • Effects of changing environmental conditions on degradation and toxicity. • Identification of factors influencing resistance. • Effects on sediments and ecological processes. • Interactions with other compounds.

* Italicised text in this table is defined in chapter 1 – Introduction.

Summary
See Section 10.2.1.2.

10.3.2.3 Effects associated with plastic debris

See Section 10.2.1.4.

10.3.3 Factors relating to all chemical effects

The extensive use of new treated timber can temporarily increase the load of CCA in the environment. Metals from treated timber are likely to bind to sediments after their release and be deposited locally, with overseas studies describing elevated concentrations in seabed sediments immediately adjacent to treated piles (Weis et al. 1993). Toxicity is strongly influenced by the physico-chemical properties of water and sediments; there is evidence that availability of compounds decreased in seawater (Rodgers & Furones 2009).

10.3.4 Impact mitigation and management strategies

10.3.4.1 Mitigation

Contaminant release from treated timber in seawater is reported to decrease exponentially over time (Brooks 1997). It is unlikely that the normal use of properly treated CCA products in reasonably well flushed marine environments will impact marine fauna or flora. There is an increasing trend overseas to use alternative construction materials.

Any management approach that reduces the likelihood of the use of therapeutants or antibiotics (e.g., disease resistance transgenics, control of stock movements) will decrease the chances of ecological impacts.

10.3.4.2 Environmental quality standards

Trigger values for CCA from various government agencies guidelines (ANZECC, NOAA, FDEP, SEPA) are provided in Appendix 10.1 (sediments) and Appendix 10.2 (water column). There are also strict regulatory guidelines around the use of treated timber for oyster farm structures (e.g., DPI 2008).

See also Section 10.2.3.1.

10.3.5 Knowledge gaps

The main knowledge gaps for antibiotics are their persistence in the environment and the effects on non-target organisms. Accumulation in the sediments may affect natural sedimentary processes, such as biogeochemistry, and it would be prudent to confirm this and to determine threshold effect levels. This could be done either in mesocosm experiments with field validation through targeted assessments, perhaps in conjunction with measurement of biotic loading and resistance. Also, new species for aquaculture will have their own native parasites and diseases, leading to novel fish health issues requiring different treatments.

10.4 Lower trophic level species

The literature outlines that the most common and growing lower trophic level technologies are for algae (algaculture) and holothurian (sea cucumbers) cultures.

Algaculture uses mainly three cultivation methods: nets and monolines (where algae are attached to frames with nylon) and ponds.

Holothurians are cultivated either in ponds, in open water in bottom-oriented cages made of steel covered with mesh (Slater & Carton 2007; Keeley et al. 2009), or in larger pens with mesh buried at the edges (Pitt & Duy 2004).

10.4.1 Overview of chemical effects

The cultivation of holothurians in hatcheries in higher density than in natural conditions may induce exceptional outbreaks of diseases, requiring the use of therapeutants (mainly antibiotics) (Eeckhaut et al. 2003). These compounds may have impacts on other aquatic organisms and their habitats; concerns with their use are mainly with the potential of these compounds to affect non-target organisms and increase resistant bacteria or parasites.

CCA-treated timber could be used for pen construction and could release metals into the sediments and provoke long-term toxicity.

Farming equipment can produce plastic debris that can have a long-term impact, depending of the type of plastic used. Ingestion by animals of plastic debris can have long-term toxicity due the potential release of plasticisers in the organism. These plasticisers are known to have endocrine-disrupting effects (the mechanical effects of plastic debris are described in Chapter 4 – Effects on marine mammals).

10.4.2 Descriptions of main effects and their significance

10.4.2.1 Antibiotics

See Section 10.2.1.2.

10.4.2.2 Copper, chromium and arsenic treated timber

See Section10.3.2.1.

10.4.2.3 Plastic debris

See Section 10.2.1.4.

10.4.3 Impact mitigation and management strategies

See Section 10.2.3.

10.4.4 Knowledge gaps

Antibiotics: See “Antibiotics” paragraph in Section 10.3.5.

CCA-treated timber: See Section 10.3.2.1.

Plastic debris: See Section 10.2.1.4.

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Appendix 10.1: Metals and metalloid trigger values in sediment for various government agencies

		Trigger values (mg/kg dw)			
		Copper	**Chromium**	**Arsenic**	**Zinc**
ANZECC	ISQG-Low	16	26	6	200
	ISQG-High	110	110	33	410
NOAA	Effect range (low)	34	81	8.2	150
	Effect range (medium)	270	370	70	410
FDEP and Canada	Threshold effects level	18.7	52.3	7.24	124
	Probable effects level	108	160	41.6	271
Netherlands	Target	36	n/a	29	
	Maximum permissible concentration	73	n/a	55	
SEPA	Background	16			
	Outside AZE	34			150
	AZE possible adverse effects level	108			270
	AZE probable adverse effects level	270			410

Appendix 10.2: Metals and metalloid trigger values in sea water

	Trigger value (µg/L)	Reliability[1]
Copper	1.3	High
Chromium III	10	Medium
Chromium VI	4.4	High
Arsenic III	2.3	Low
Arsenic V	4.5	Low
Zinc	15	High

[1]The grade depends on the data available and hence the confidence or reliability of the final figures (Warne 1998)