REVIEW ARTICLE

An assessment of the use of drug and non-drug interventions in the treatment of *Ichthyophthirius multifiliis* Fouquet, 1876, a protozoan parasite of freshwater fish

S. M. PICÓN-CAMACHO[1]*, M. MARCOS-LOPEZ[2], J. E. BRON[1] *and* A. P. SHINN[1]

[1] *Institute of Aquaculture, University of Stirling, FK9 4LA Stirling, UK*
[2] *Marine Laboratory, 375 Victoria Rd, AB11 9DB Aberdeen, UK*

(*Received 17 June 2011; revised 12 September 2011; accepted 16 September 2011; first published online 14 November 2011*)

SUMMARY

Infection by the ciliate protozoan *Ichthyophthirius multifiliis* Fouquet, 1876 causes significant economic losses in freshwater aquaculture worldwide. Following the ban on the use of malachite green for treating food fish, there has been extensive research aimed at identifying suitable replacements. In this paper we critically assess drug and non-drug interventions, which have been tested for use or have been employed against this parasite and evaluate possibilities for their application in farm systems. Current treatments include the administration of formaldehyde, sodium chloride (salt), copper sulphate and potassium permanganate. However, purportedly more environmentally friendly drugs such as humic acid, potassium ferrate (VI), bronopol and the peracetic acid-based products have recently been tested and represent promising alternatives. Further investigation, is required to optimize the treatments and to establish precise protocols in order to minimize the quantity of drug employed whilst ensuring the most efficacious performance. At the same time, there needs to be a greater emphasis placed on the non-drug aspects of management strategies, including the use of non-chemical interventions focusing on the removal of free-swimming stages and tomocysts of *I. multifiliis* from farm culture systems. Use of such strategies provides the hope of more environmentally friendly alternatives for the control of *I. multifiliis* infections.

Key words: *Ichthyophthirius multifiliis*, whitespot, drug, treatment, ciliate, parasite.

INTRODUCTION

The freshwater protozoan parasite of fish, *Ichthyophthirius multifiliis* Fouquet 1876, also known as 'fish whitespot', continues to impact wild and cultured fish populations worldwide and places an economic burden on global freshwater finfish aquaculture.

The ciliate protozoan *I. multifiliis* is one of the most important freshwater pathogens affecting the aquaculture and ornamental fish industries. In part, its impact stems from its low host specificity, allowing it to infect a wide range of fish species, including commercially important species such as channel catfish (*Ictalurus punctatus* Rafinesque 1818) and rainbow trout (*Oncorhynchus mykiss* Walbaum 1792) (see Valtonen and Koskivaara, 1994; Noble and Summerfelt, 1996; Buchmann and Bresciani, 1997; Rintamäki-Kinnunen and Valtonen, 1997; Matthews, 2005; Jørgensen *et al*. 2009). It has a direct life cycle, which is temperature dependent such that the warmer the water temperature the faster the life cycle completes. The life cycle involves 4 different stages: (1) the trophont, which resides within the surface epithelium of gills, fins and other body surfaces; (2) the protomont, a free-swimming stage that exits the fish and settles on the substrate to become the encysted tomocyst stage (3) which in turn repeatedly divides by binary fission to produce tomites which are released to the water column. Tomites differentiate into the infective stage (4) the theront, which needs to find a host within a short window to successfully complete the life cycle by penetrating the epidermis and developing into the trophont stage before it dies (Lom and Dyková, 1992; Matthews, 2005). Theronts can survive for up to 92 h at low water temperatures; their survival being inversely proportional to the ambient water temperature (Wagner, 1960; Aihua and Buchmann, 2001).

On farms, the most common approaches to treat this ciliate is through the use of either short (e.g. 30 min–4 h in tanks, raceways and flow-through systems) or long (e.g. 7–15 days in pond culture) duration in-bath treatments which target the free-swimming stages of the parasite (i.e. protomonts and theronts). Of the other two stages, the trophont is protected lying underneath the host surface

* Corresponding author: Gulf Coast Research Laboratory, University of Southern Mississippi, Ocean Springs, MS 39564, USA. Tel: +228 818 8807. E-mail: sarapicon@yahoo.es

doi:10.1017/S0031182011001867

epithelium (Post and Vesely, 1983) whilst the tomocyst is protected by a resistant coat (Ewing *et al*. 1983) and as such, are rarely susceptible to treatment.

Historically, malachite green (MG) was commonly used for the control of *I. multifiliis* and a range of other fish diseases (Srivastava *et al*. 2004) due to its demonstrable efficacy, low cost, ready availability, high stability during storage and high solubility in water (Schnick, 1988; Henderson *et al*. 1997). This organic (triphenylmethane) dye was favoured for the control of *I. multifiliis* infections because of its high efficacy against both the free-swimming stages (protomonts and theronts) of the parasite and the feeding parasite stage (trophont) within the fish's epithelium (Wahli *et al*. 1993; Tieman and Goodwin, 2001; Buchmann *et al*. 2003). MG and its derivatives (mainly leucomalachite) also display well-documented ecotoxicological effects including cytotoxicity, carcinogenicity, mutagenicity, induction of chromosomal fractures, teratogenicity and respiratory toxicity (Culp and Beland, 1996; Srivastava *et al*. 2004). Malachite green and its derivatives are also known to be highly persistent in the environment, bio-accumulating in the ecosystem and fish tissues (Henderson *et al*. 1997). Although the use of MG has never been licensed by the US Food and Drug Administration (FDA), its use in food products was initially permitted under an 'investigational new animal drug' status (Alderman, 1985). This status was revoked in 1983 and MG was listed as a priority chemical for toxicity and carcinogenicity testing (Culp and Beland, 1996; Culp, 2004). Similarly, in Canada the use of MG and the presence of its derivatives in food animals are not permitted and its continued use was advised against in 1992 when MG was classified as a class II health hazard (Canadian Food Inspection Agency 2010). Its use within the European Union has been subsequently banned in 2000 under EC directive 90/676/EEC; article 14, regulation 2377/90/EEC.

As a consequence of the widespread ban, enforced restrictions imposed on the use of MG and the concerns regarding the presence of derivatives in food-products (Herber, 2009), there has been extensive research in the last few decades focusing on the provision of alternative, effective and environmentally friendly products and management techniques for controlling *I. multifiliis* infections. Despite the global effort, no clear alternative management strategies have yet emerged. There is a strong commercial and scientific need for providing a critical summary of tested candidate and applied drugs but also an assessment of the potential of other management strategies to prove efficacious against *I. multifiliis* infections. It has been nearly 30 years since the last major reviews were published examining the use of drugs for the control of *I. multifiliis* (Cross, 1972; Hoffman and Meyer, 1974; Herwig, 1979) so that this review might be considered to be somewhat overdue.

This paper provides an overview and assessment of the current state of knowledge concerning drugs (compound, dose, duration and efficacy) and physical interventions employed or tested against *I. multifiliis* since the 3 earlier reviews were published. This review seeks to summarize the original research findings and to help identify the most suitable therapy against *I. multifiliis* while highlighting the most promising treatments for further research and application in farm systems.

ASSESSMENT OF CURRENTLY APPLIED CHEMOTHERAPIES

A large number of compounds have been tested for efficacy against *I. multifiliis* although relatively few of them have been widely deployed to provide effective control under field conditions. Table 1 provides a detailed list of 116 compounds used to control *I. multifiliis* under laboratory or field conditions from 1980 onwards. Of the compounds that are listed, all except quinine and some malachite green-based formulations have been tested against food fish species. These latter treatments, however, that have been evaluated for the ornamental trade, are included to provide a comprehensive overview of all compounds tested for the treatment of *I. multifiliis*. Of those given in Table 1, 18 entries listed by their commercial product name are cross-referenced, and details of their activity given, under their specific compound formulation. Sixteen of the compounds have been assessed by *in vitro* trials only, while of the remaining 81 compounds tested *in vivo*, 43 have been tested in-bath challenges and 51 by in-feed presentation. Of those used under field conditions, the most commonly used treatments are: formaldehyde, sodium chloride, copper sulphate, potassium permanganate, chloramine-T, hydrogen peroxide, metronidazole and toltrazuril (Dickerson, 2006; Noga, 2010). Whilst malachite green was previously the most extensively employed treatment, eliminating the protomont, theront and trophont stages, its use has been largely discontinued for food fish, particularly in the EU and the United States.

Some caution, however, should be taken with regard to the treatment efficacies provided in Table 1, in that these may be the result of how the study was conducted (i.e. natural, multi-age class infections compared to a standard, single age class infection) and/or evaluated (i.e. parasite numbers determined from skin scrapes as opposed to total parasite counts) and therefore the results may have been affected by the differential level of parasitaemia at the time of the treatment on the test and control fish. For efficacious compounds of interest, therefore, details on the treatment conditions used in the original work should be consulted. If the physiological trauma created by

exiting trophonts is considered as the primary cause of mortality, then a compound that successfully kills trophonts *in situ*, thereby preventing exit, could be considered efficacious (i.e. a statistically lower number of parasites and host mortality when compared to an appropriate control group).

Formaldehyde

Formaldehyde has been proven to be very effective at eliminating the free-living stages of the parasite (i.e. protomonts, tomocysts and theronts) (Wahli *et al*. 1993; Shinn *et al*. 2005, Lahnsteiner and Weismann, 2007; Heinecke and Buchmann, 2009), however, when used for *in vivo* baths, fish survival can be compromised (Wahli *et al*. 1993; Tieman and Goodwin, 2001). Formaldehyde remains one of the most commonly used treatments to control *I. multifiliis* infections in aquaculture systems (Noga, 2010). However, efficiency is achieved only at high concentrations, which are serially repeatedly applied (i.e. 100 mg l^{-1} for 30 min to 1 h over 10 consecutive days in salmonid farms), such that in flow-through systems with rapid water turn-over, as used for e.g. the intensive production of salmonids, high volumes are required. In addition, the use of formaldehyde has many reported side effects such as reducing the oxygen available in the water by 1 ppm for each 5 ppm of formaldehyde that is used (Cross, 1972; Pillay and Kutty, 2005). This can be particularly problematical in summer when increasing water temperatures both accelerate the life cycle of *I. multifiliis* and act to cause a concomitant reduction in the oxygen holding capacity of the water. Buchmann *et al*. (2004) also demonstrated that *O. mykiss* exposed to formaldehyde at concentrations of 200–300 ppm for 1 h had a reduced mucus production and were thus more susceptible to secondary infections by water moulds and bacteria. Accordingly, when formaldehyde is applied *in vivo* in the form of baths, fish survival can be compromised (e.g. for *O. mykiss* exposed to 2 treatments of 25 and 100 mg l^{-1} of formaldehyde for 1 h on days 9 and 12 post-infection) (Wahli *et al*. 1993). Importantly, the effect of water quality parameters on the toxicity of formaldehyde to fish and to *I. multifiliis* remains poorly characterized (Meinelt *et al*. 2005). Although formaldehyde is an approved aquacultural therapeutic within the EU (Schlotfeld, 1993, 1998), in 2004 it was re-classified by the WHO International Agency for Research on Cancer as 'carcinogenic to humans' (WHO, 2006). Even though it is quickly metabolized by aquatic organisms and holds a low potential for bio-accumulation (Hohreiter and Rigg, 2001; Duffort *et al*. 2010), it might be envisaged that formaldehyde could soon be banned due to the hazard it poses to workers handling large volumes of the chemical (Wooster *et al*. 2005). Given the high volumes of formaldehyde required in a typical farm treatment and the potential toxic risks this chemical poses to both fish stock and the farm workers handling it, the future of formaldehyde as a long-term acceptable and sustainable drug seems unlikely.

Sodium chloride

Sodium chloride (salt) is the second most commonly used product for the treatment of *I. multifiliis* infections. The application of a minimum of 2·5 g l^{-1} has been proven to reduce protomont and theront survival (Aihua and Buchmann, 2001; Shinn *et al*. 2005; Lahnsteiner and Weismann, 2007). A treatment regime of 1–5 g l^{-1} salt applied continuously for a minimum period of 7 to 32 days, for example, was able to reduce the number of trophonts establishing on fish (Selosse and Rowland, 1990; Miron *et al*. 2003; Lahnsteiner and Weismann, 2007; Balta *et al*. 2008; Mifsud and Rowland, 2008). The use of higher concentrations of salt (e.g. 15–20 g l^{-1}) over short periods of exposure (e.g. 20–60 min), however, was not able to reduce the level of infection (Lahnsteiner and Weismann, 2007; Balta *et al*. 2008). Additionally, the bath application of salt may be beneficial, in helping the host recover the osmotic imbalance and loss of salts created by exiting trophonts. The incorporation of salt in fish feed has also been explored with contradictory results. Rahkonen and Koski (2002) reported a reduction in infection levels in medicated fish when salt was incorporated at a level of 0·3–1·0% and fed for 3 to 11 days. Garcia *et al*. (2007), however, did not observe any significant reduction in parasite burdens when fish were fed a diet containing 1·2–6·0% salt for a period of 30 days. While the use of salt appears to represent an economically viable and safe treatment option for many farm and ornamental fish species, it should be used with caution in certain infected stenohaline freshwater fish species such as channel catfish (Noga, 2010).

Copper sulphate

Copper sulphate has been shown to be effective at eliminating *I. multifiliis* in a range of fish species when used at low concentrations (Ling *et al*. 1993; Schlenk *et al*. 1998; Goodwin and Straus, 2006; Straus, 2008; Rowland *et al*. 2009). However, long periods of exposure can lead to toxicity, gill damage and growth suppression (Cardeilhac and Whitaker, 1988; Moore, 2005; Rábago-Castro *et al*. 2006). Copper has a very low therapeutic index (Boyd, 2005) and its toxicity to both fish host and *I. multifiliis* is known to vary widely with water chemistry parameters, particularly water alkalinity and hardness (Deilhac and Whitaker, 1988; Straus, 2008; Straus and Meinelt, 2009). Copper sulphate is a recognized algaecide and is known to be toxic to a

wide range of invertebrate organisms (Boyd, 1990). When added to pond systems, there is a risk of phytoplankton mortality which consequentially might result in lower oxygen levels at night, which in turn compromises the trophic chain on which the fish stock might rely (Noga, 2010). It is vital therefore that its use on a small subsample of the fish stock in the local water is determined before it is applied on a large-scale basis. Particular care should be taken when using this compound in green water pond systems. Future research should be aimed at identifying the range of water quality parameters and concentrations within which this compound is effective against *I. multifiliis* infections and can be safely administered without risk to fish.

Potassium permanganate

Potassium permanganate ($KMnO_4$) is also commonly used against *I. multifiliis*, mainly in farm pond systems (Brown and Gratzek, 1980; Noga, 2010). Low concentrations (e.g. 0·8–1·0 mg l^{-1}) over short periods of exposure (30 min to 4 h) were able to eliminate the theront stage in the water column (Straus and Griffin, 2001). When tested *in vivo*, low concentrations (e.g. 0·25–2 mg l^{-1}) require longer periods of exposure (continuously from 6 to 20 days) to significantly decrease the number of trophonts per fish (Tieman and Goodwin, 2001; Straus and Griffin, 2001, 2002). The application of higher concentrations (e.g. 10–20 mg l^{-1}) for 30 min was found to be toxic to treated fish (Balta *et al*. 2008). Potassium permanganate is an algaecide which oxidizes organic matter, reducing dissolved oxygen levels; its effects are notable when used in ponds. This compound has a low therapeutic index and can be very toxic when used in waters of a high pH when it can precipitate on gills leading to high mortalities (Tucker, 1987; Dolezelova *et al*. 2009; Noga, 2010). Potassium permanganate treatment against *I. multifiliis* shows very low efficacy at concentrations that are not toxic to fish, if the organic loading of the aquatic system is not taken into account. Large quantities of this compound and its continuous application, therefore, are often required to manage infections.

Chloramine-T

Chloramine-T is an organic chlorine compound, specifically a sodium salt that when mixed with water is a very strong disinfectant (Treves-Brown, 2000; Noga, 2010). When used to treat *I. multifiliis* stages, chloramine-T has been found to be very effective *in vitro* for the treatment of both the protomont and theront stages (Shinn *et al*. 2001). *In vivo*, however, chloramine-T was effective only when administered at high concentrations (e.g. 100 mg l^{-1} for 30 min given over a period of 10 days) (Shinn *et al*. 2001; Tieman and Goodwin, 2001; Rahkonen and Koski, 2002; Shinn *et al*. 2003*a*; Rintamäki-Kinnunen *et al*. 2005*a*; Balta *et al*. 2008). The administration of high doses of chloramine-T can inflict damage to the gill epithelia and has been reported to affect the development of the swim bladder in young fry (Sanabria *et al*. 2009). The average lethal time (LT_{50}) for a dose of 50 mg l^{-1} chloramine-T was determined to be 166·8 min (Powell and Harris, 2004). Although these latter authors suggested that freshwater stages of Atlantic salmon, *Salmo salar* L., were as sensitive to chloramine-T toxicity as *O. mykiss,* and more sensitive than *I. punctatus,* the latter showed histopathological changes when exposed daily to 80 mg l^{-1} in a static immersion bath for 3 h (Gaikowski *et al*. 2009). Future work, therefore, should explore the efficacy of using 30 min baths of chloramine-T ranging between 30 and 80 mg l^{-1} over a period of 10 days (e.g. treatments on days: 1, 4, 7 and 10) (or the full duration of the parasite life cycle as dictated by the ambient water temperature).

Hydrogen peroxide

Hydrogen peroxide is a powerful oxidizer that has been used under field conditions to control *I. multifiliis*. Results for its use in *in vitro* tests against free-living stages of *I. multifiliis*, however, were disappointing (Shinn *et al*. 2005; Lahnsteiner and Weismann, 2007), with a 100 mg l^{-1} treatment for 1 h effecting only a 15% mortality of theronts (Shinn *et al*. unpublished observations). It is not surprising, therefore, that a 20-day regime of 25 mg l^{-1} hydrogen peroxide failed to bring about a reduction in the number of trophonts on stock, which consequentially resulted in high mortalities (Tieman and Goodwin, 2001). High doses, however, can cause gill damage leading to fish mortality (especially at high temperatures) (Schmidt *et al*. 2006; Noga, 2010).

Metronidazole

Metronidazole has been shown to be very successful at reducing the number of trophonts on infected fish when incorporated into diets (Tojo-Rodriguez and Santamarina-Fernandez, 2001; Tokşen and Nemli, 2010). This compound, which has been shown to be effective in the ornamental fish industry, is currently listed as being 'possibly carcinogenic to humans' by the World Health Organization and has been banned within the EU and USA for use in animal feed; in the US specifically for animals destined for human consumption. Its future use as a potential treatment in the fish food industry, therefore, is no longer considered.

Toltrazuril

The triazinetrione derivative coccidiostat toltrazuril has been shown to be effective against the protomont

stage in *in vitro* trials (Schmahl *et al*. 1989; Tojo-Rodriguez *et al*. 1994). However, when administrated *in vivo* it is either ineffective (Schmahl *et al*. 1989; Tojo-Rodriguez *et al*. 1994) or toxic to the fish (From *et al*. 1992).

THE POTENTIAL OF ALTERNATIVE CHEMICAL COMPOUNDS

Despite recent extensive research to explore the utility of alternative, environmentally friendly chemical compounds, only a handful of compounds have been shown to display efficacy at reducing *I. multifiliis* infections *in vivo* (see Table 1).

In-bath treatments

Of the bath compounds that have been identified, acetic acid (4%), bronopol, peracetic acid-based products, combinations of peracetic acid and formaldehyde, humic acid (10%) and potassium ferrate (VI) displayed a good level of efficacy. Acetic/peracetic acid represents the cheapest treatment option, followed by, in rank order, formaldehyde, potassium ferrate (VI), and then significantly more expensive bronopol and humic acid, notably the latter. Of these compounds, acetic acid (4%) is widely used in Turkey to control protozoan infections (Kayis *et al*. 2009). When tested *in vivo* against *I. multifiliis*, a single short dip bath of 10 ml l^{-1} for 3 min was able to reduce the trophont burden on treated fish (Balta *et al*. 2008).

Bronopol, the active compound of a product already licensed for use as an aquacultural drug, when applied at low concentrations (e.g. 2 and 5 mg l^{-1}) over a long period of exposure (e.g. 27 days) was demonstrated to be highly effective against the free-swimming stages of *I. multifiliis*, as well as reducing the number of trophonts subsequently establishing in successive waves of infection (Shinn *et al*. 2011; Picón-Camacho *et al*. 2011*a*). Bronopol does not accumulate in fish tissues or in the environment and therefore no withdrawal period is required after its administration (Novartis, 2002). Bronopol presents no serious toxicological hazard to humans (Bryce *et al*. 1978) or to fish (Pottinger and Day, 1999), and, it degrades very quickly, especially when exposed to high intensity UV light (Noga, 2010). Bronopol-based products therefore show strong potential for the management of *I. multifiliis* infections in farm systems; however, timing of deployment with respect to parasite population dynamics and optimal treatment concentrations remain to be optimized for this product.

Formulations of peracetic acid (PAA), hydrogen peroxide and acetic acid have proven able to kill the protomont stage within 48 h of exposure at concentrations of 0·8–0·9 mg l^{-1}. Importantly, tomocysts recently attached to the substrate were also killed following a 12 h exposure to 1–3 mg l^{-1} to PAA solutions (Meinelt *et al*. 2009). When used *in vivo*, formulations containing a high proportion of PAA were also able to reduce the number of trophonts on infected fish (Rintamäki-Kinnunen *et al*. 2005*a*; Sudová *et al*. 2010). Adding peroctanoic acid to a PAA formulation, further improved the anti-protozoal activity of the solution, such that tomocyst stages were killed after 60 min exposure (Bruzio and Buchmann, 2010; Picón-Camacho *et al*. 2011*b*). PAA's stability, however, has been shown to be closely linked to a range of water quality parameters such as temperature, organic matter content and pH (Pedersen *et al*. 2009) and therefore the degradation of PAA must be assessed over time and taken into account in establishing the most effective treatment regime to use on site. The efficacy of PAA, notably against the tomocyst and trophont stages, however, highlights the potential of this compound as a treatment against *I. multifiliis*.

Low concentrations of humic acid (10%) (100–150 μl l^{-1}) were found to disrupt the development of protomonts; however, when the same concentrations were used *in vivo*, the results were inconsistent and appeared to be highly dependent on water temperature and the treatment regime used (Lahnsteiner and Weismann, 2007).

Ling *et al*. (2010) demonstrated that 4·8 mg l^{-1} potassium ferrate (VI) for 2 h was very effective *in vitro*, in killing theronts. When the same dose was used as an *in vivo* continuous bath treatment for 3 days, it resulted in an 80% reduction in the number of trophonts on the test fish. An increase in concentration to 19·2 mg l^{-1} applied for 3 days managed to completely eradicate the infection from the fish stock suggesting that potassium ferrate (VI) is very successful at disrupting trophont development. Potassium ferrate (VI) is an environmentally friendly, strong oxidizing agent (Ma and Liu, 2002), that is less toxic to fish and humans than closely related potassium salts such as potassium permanganate (Ling *et al*. 2010). The effectiveness and degradation rate of potassium ferrate (VI) in the aquatic environment, however, is strongly linked to pH and water temperature (Johnson and Sharma, 1999) and these must be considered when establishing a treatment regime based on its use.

Of the bath chemicals that have investigated in recent years, potassium ferrate (VI), bronopol and the peracetic acid-based products all possess potential as promising alternatives to current chemotherapies for the control of *I. multifiliis* infections.

In-feed treatments

Of the in-feed treatments described in Table 1, the compounds with the highest apparent efficacy *in vivo* in controlling *I. multifiliis* infections are amprolium

hydrochloride, vitamin C, quinine, SalarBec, salinomycim sodium and secnidazole. Shinn *et al*. (2003*b*) demonstrated that the two anti-coccidiostats compounds, amprolium hydrochloride and salinomycin sodium, when incorporated into a commercial feed, were able to significantly reduce the number of trophonts establishing on fish. Treatment with 100 mg l^{-1} of amprolium hydrochloride (a thiamine, vitamin B1, analogue) for 1 h compromised the survival of the tomocyst stage *in vitro*, ultimately killing 85–90% of the tomocysts (Shinn *et al*. 2001). Incorporation of 1 g kg^{-1} of feed given over 8 days post-infection did not manage to reduce the trophont burden on fish (Tojo-Rodriguez *et al*. 1994). A dose 63 mg kg^{-1} of feed of amprolium hydrochloride given 10 days prior the infection, however, reduced the number of trophonts subsequently establishing on fish by up to 78% when compared to the control groups (Shinn *et al*. 2003*b*). Salinomycin sodium has only been tested *in vivo*, with promising results. Infected fish fed a diet containing 47–63 mg kg^{-1} of feed of salinomycin sodium for a period of 10 days were found to show a significant reduction (80–93%) in number of trophonts when compared to the control groups (Shinn *et al*. 2003*b*). The same authors also tested SalarBec, a blend of Vitamin C, E and B group. When SalarBec was incorporated at a rate of 3·2 g kg^{-1} feed and given to fish for a period of 10 days prior to infection with *I. multifiliis,* a 65% reduction in the number of trophonts surviving on challenged fish was found (Shinn *et al*. 2005).

Vitamin C on its own or in combination with Vitamin E has also been tested with success *in vivo* (Wahli *et al*. 1985, 1995, 1998). Quinine when incorporated into feed at a rate of 5 g kg^{-1} feed and given over a period of 7 to 10 days effected the complete elimination of *I. multifiliis* on medicated fish (Schmahl *et al*. 1996). Medicated fish using vitamin C and quinine, however, showed growth suppression as a result of decreased food intake.

Finally, secnidazole is an antibiotic which has been shown to reduce *I. multifiliis* infections when incorporated into feed and presented at 24–36 mg kg^{-1} of body weight (Tokşen and Nemli, 2010) or 40 g kg^{-1} of feed for 10 days (Tojo-Rodriguez and Santamarina-Fernandez, 2001). While secnidazole appeared to be effective, the cost of using it on a large commercial scale would be prohibitive (Noga, 2010).

Although the use of in-feed treatments appears to be an efficient, targeted strategy for reducing trophont burdens, the general inappetance displayed by heavily infected fish means that getting the target dose into infected fish in the later stages of an infection can be a challenge. This can, in part, be circumvented by top dressing unpalatable medicated diets (e.g. salinomycin sodium, see Shinn *et al*. 2003*b*) with bait flavouring to mask bitter ingredients and/or by incorporating feed stimulants (e.g. garlic) into the diet (Shinn unpublished data).

NATURAL EXTRACTS

Some new treatments involve the use of plant extracts such as those from garlic, *Allium sativum* L., which showed promising results when tested *in vitro* (Buchmann *et al*. 2003). However, when incorporated in-feed and tested *in vivo* this extract did not manage to significantly reduce infection levels when compared to control groups (Shinn *et al*. unpublished observations). Other natural products such as those from papaya *Carica papaya* L. and the velvet bean *Mucuna pruriens* L. were successful when tested *in vitro* and *in vivo* against protomonts and trophonts (Ekamen *et al*. 2004). Concentrations of 200 and 250 mg l^{-1} of *C. papaya* reduced the infection levels on treated fish by 89–92%. *M. pruriens* administered at 100, 150 and 200 mg l^{-1} also reduced the parasite burden on the treated fish by 59–92%. Recent research by Yao *et al*. (2010) using the extract from *Macleaya cordata* Willd has shown high efficacy in *in vitro* trials against protomonts and an important trophont reduction (e.g. 75–97%) when administered *in vivo* at low concentrations (e.g. 0·6–0·9 mg l^{-1}) for 48 h. The use of probiotics as an in-feed treatment (e.g. 10^8 cells of *Aeromonas sobria* g^{-1} feed for 14 days) has also proven to be very effective at reducing infections in medicated fish (Pieters *et al*. 2008).

There may therefore be considerable potential for the use of such natural products to control *I. multifiliis* infections; however, *in vivo* trials carried out under field conditions are a critical requirement prior to wider deployment of such treatments.

NON-DRUG INTERVENTIONS

In the last few years, a wide range of non-drug interventions (see Table 2) have been tested against *I. multifiliis*.

Farley and Heckmann (1980) used 'electrotherapy' as a possible treatment to control whitespot infections. Whilst there was some protomont mortality following exposure to short pulses of electricity (5 sec), it seems that this was probably due to water hydrolysis rather than lysis of the parasite. It was concluded that the amperage necessary to disrupt trophonts within the fish epidermis would be too high and lethal to the fish.

The utilization of a single UV lamp (91900 $\mu W\,s^{-1}\,cm^{-2}$) has, in contrast, successfully managed to reduce the mortality of fish infected with *I. multifiliis* in a closed re-circulation system by controlling the spread of *I. multifiliis* stages between tanks (Gratzek *et al*. 1983).

The mechanical filtration of inlet water, considering that the size of theronts ranges from

57·4 × 28·6 μm (at 5 °C) and 28·6 × 20·0 μm (at 30 °C), is not a feasible method to prevent the entry of the parasite to farm systems (Aihua and Buchmann, 2001). Nonetheless, a combination of an 80 μm mesh followed by a treatment of sodium percarbonate prevented protomonts from entering the system and killed theronts (Heinecke and Buchmann, 2009).

Bodensteiner *et al*. (2000) demonstrated that increasing the flow rate and water turnover in fish farms above 85 cm min^{-1} and 2·1 l h^{-1} managed to reduce infection levels by flushing the free-swimming stages of the parasite out of the system. However, since water availability in farms can fluctuate greatly over the year, often reducing significantly over the summer months at the same time as water temperature increases exacerbate *I. multifiliis* infections, this cannot always provide a viable control solution.

Shinn *et al*. (2009) recently demonstrated that the combination of regular cleaning with a vacuum cleaning head and the use of a low adhesion polymer to line rainbow trout raceways is able to remove tomocysts and reduce infection levels by up to 99·55% when compared to control groups. Notwithstanding their apparent efficacy, none of the management strategies described above have been adopted so far in a commercial fish farm context.

Despite these non-drug interventions, fish that are exposed to a certain level of *I. multifiliis* infection are able to acquire a protective immunity which can last from several months to a year (Hines and Spira, 1974; Burkart *et al*. 1990; Matthews, 1994). This acquired immunity has stimulated efforts towards the development of a vaccine against *I. multifiliis* which is in progress (Matthews, 2005; Sommerset *et al*. 2005; Dickerson, 2006).

CONCLUSION

Currently, the most frequent method employed to control *I. multifiliis* infections in farm systems is the use of in-bath chemical treatments. Because of its asynchronous life cycle and continuous release into the water column of different stages (Lom and Dyková, 1992; Matthews, 2005), multiple applications are often required over long periods of time, notably during the summer months when water temperatures can rise rapidly. In addition, outbreaks can occur in the spring and autumn seasons during which sharp changes in water temperature can induce physiological stress, as seen in channel catfish pond culture (Noga, 2010). Such treatment regimes involve the use of large quantities of chemicals when the infections levels are high (e.g. formaldehyde and sodium chloride), leading to high costs and potentially high environmental impacts. Repeated or prolonged use of a single drug without rotation of treatment types is also likely to increase the probability of development of drug resistance in the targeted pathogen, as documented for bacterial and copepod fish pathogens (Fallang *et al*. 2004; Lees *et al*. 2008; Heuer *et al*. 2009). While development of resistance by *I. multifiliis* has yet to be investigated, it is clear that drug resistance would act to increase the quantities of drug used and the environmental impacts of treatment.

In the present overview we have assessed the efficacy and practicality of a wide range of drug and non-drug strategies that are potentially available to be used in farm systems. However, there remain considerable difficulties in comparing efficacies between products, since no standardized methods are employed across the stakeholder community for culturing the parasite, assessing viability of the theront stage and infecting fish. The greatest current discrepancy in determining the efficacy of a treatment follows from the counting method employed for enumerating the trophont stage in *in vivo* studies. Some researchers only consider the trophonts present on skin scrapes or gills while others take into the account direct observations of the number of visible trophonts present in skin, fins and gills. In addition to these methodological variations, there is the fact that different strains/genotypes of *I. multifiliis* can behave very differently in terms of infectivity (Elsayed *et al*. 2006; Swennes *et al*. 2007; Ling *et al*. 2009), host specificity and susceptibility to treatment (Straus and Meinelt, 2009; Straus *et al*. 2009). Hence, a chemical treatment demonstrated to successfully eliminate one strain might not exhibit the same efficacy when applied to treat a different one.

From this review, chemical treatments remain the principal method for controlling *I. multifiliis* infections in aquaculture, despite numerous attempts to develop and implement physical and farm management-based alternatives. With the introduction of a ban on the use of malachite green in food-fish and a likely future ban on the use of formaldehyde, options for effective drug treatment remain severely depleted. For these reasons, considerable research has been conducted to develop new drugs or screen existing compounds, both natural and synthesized, for efficaciousness against one or more stages of this parasite. New products, where deployed, will need to be derived from sustainable sources and of themselves be more environmentally friendly and more suitable for use in food-fish than previous compounds. As part of the attempt to reduce the use of drugs, new deployment strategies (e.g. extended low-dose treatments), management strategies helping to reduce initial infection levels (e.g. flow control), breeding fish for resistance and the development of DNA vaccines need to be considered.

FINANCIAL SUPPORT

Part of this study was supported by the British Federation of Women in Science (BFWS) awarded to Sara Picón Camacho to support her Ph.D. project.

Table 1. Chemical treatments tested against infections of *Ichthyophthirius multifiliis* Fouquet, 1876

(A compound is regarded as being partially effective if it kills 50–80%, and effective if it kills ⩾80% of the stages under test. Mortality refers to the parasite stages unless otherwise stated.)

Compound	Dose	Host/parasite stage	Efficacy	Reference
Acaprin (1, 3-di-6-quinolylurea)				
In vitro	200 mg l^{-1} for 2 h	Protomonts	Partially effective – 62·5% mortality after 1–2 h 60% of surviving protomonts develop normally	Tojo-Rodriguez *et al*. (1994)
In vivo – bath	200 mg l^{-1} for 3 h	*Oncorhynchus*	Not effective – all trophonts developed normally †	Tojo-Rodriguez *et al*. (1994)
In-feed	500 mg kg^{-1} for 8 d	*mykiss*	Not effective – all trophonts developed normally †	Tojo-Rodriguez and Santamarina-Fernandez (2001)
	40 g kg^{-1} for 10 d		Not effective – no details	
Acetic acid (4%)				
In vivo – bath	10 ml l^{-1} for 3 min	*O. mykiss* *Salvelinus fontinalis* *Salmo trutta*	Partially effective – reduction of the number of trophonts on treated fish but no details given	Balta *et al*. (2008)
Allium sativum (garlic extract)				
In vitro	0·5 mg l^{-1} for 1·5, 3 and 15 h	Theronts	Not effective – < 50% mortality	Buchmann *et al*. (2003)
	2·5 mg l^{-1} for 1·5, 3 and 15 h		Not effective – < 50% mortality	
	12·5 mg l^{-1} for 1·5, 3 and 15 h		Not effective – < 50% mortality	
	62·5 mg l^{-1} for 1·5 and 3 h		Not effective – < 50% mortality	
	62·5 mg l^{-1} for 15 h		Partially effective – > 50% mortality	
	312·5 mg l^{-1} for 1·5 h		Not effective – < 50% mortality	
	312·5 mg l^{-1} for 3 and 15 h		Partially effective – > 50% mortality	
	1562·5 mg l^{-1} for 3 and 15 h		Partially effective – > 50% mortality	
	30 mg l^{-1} for 24 h	Tomocysts	Not effective – 13% mortality	Buchmann *et al*. (2003)
	117 mg l^{-1} for 24 h		Partially effective – 53% mortality	
	570 mg l^{-1} for 24 h		Effective – 100% mortality	
Amphotericin B (dissolved in Na-desoxycholate)				
In vitro	0·25 mg l^{-1} for 24 h	Adults**	Effective – 100% mortality after 24 h	Wahli *et al*. (1993)
	2·5 mg l^{-1} for 24 h		Effective – 100% mortality after 1 h	
	0·25 mg l^{-1} for 24 h	Tomocysts	Effective – 100% mortality after 24 h	
	2·5 mg l^{-1} for 24 h		Effective – 100% mortality after 24 h	
	0·25 mg l^{-1} for 3 h	Theronts	Effective – 100% mortality after 1 h	
	2·5 mg l^{-1} for 3 h		Effective – 100% mortality after 5 min	
In vivo – bath	0·25 mg l^{-1} −2× for 1 h 1st: day 9 p.i, 2nd: day 12 p.i	*O. mykiss*	Not effective – no details	Wahli *et al*. (1993)
Amprolium hydrochloride (1-[(4-amino-2-propyl-5-pyrimidinyl) methyl]-2-picolinium chloride hydrochloride) commercialised as Amprolmix				
In vitro	20 mg l^{-1} for 1 h	Protomonts	Not effective – 10% mortality	Shinn *et al*. (unpublished)
	50 mg l^{-1} for 1 h		Not effective – 10% mortality	

	100 mg l^{-1} for 1 h		Not effective – 90% mortality	
	200 mg l^{-1} for 2 h	Protomonts	Not effective – 0% mortality after 2 h; prototomonts developed normally	Tojo-Rodriguez *et al*. (1994)
	1000 mg l^{-1} for 48 h		Not effective – survival not affected	Farley and Heckmann (1980)
	100 mg l^{-1} for 15 h	Tomocysts	Effective – 85% mortality	Shinn *et al*. (2001)
	100 mg l^{-1} for 41 h		Effective – 90% mortality	
	20 mg l^{-1} for 1 h	Theronts	Not effective – 22·4% mortality	Shinn *et al*. (unpublished)
	50 mg l^{-1} for 1 h		Not effective – 20·4% mortality	
	100 mg l^{-1} for 1 h		Not effective – 22·3% mortality	Shinn *et al*. (2001)
In vivo – bath	200 mg l^{-1} for 3 h day 6 p.i.	*O. mykiss*	Not effective – all trophonts developed normally	Tojo-Rodriguez *et al*. (1994)
In-feed	63 mg kg^{-1} feed for 10 d prior inf.	*O. mykiss*	Partially effective – 77·6% reduction in trophont numbers	Shinn *et al*. (2003*b*)
	75 mg kg^{-1} feed for 10 d p.i.		Not effective – 32·2% reduction in trophont numbers	
	75 mg kg^{-1} feed for 10 d prior inf.		Partially effective – 63% reduction in trophont numbers	Shinn *et al*. (2001)
	104 mg kg^{-1} feed for 10 d p.i.		Partially effective – 62% reduction in trophont numbers	Shinn *et al*. (2003*b*)
	1000 mg kg^{-1} feed for 8 d p.i.	*O. mykiss*	Not effective – all trophonts developed normally	Tojo-Rodriguez *et al*. (1994)
Amprolmix				
See entry for amprolium hydrochloride				
Aeromonas sobria				
In vivo – In-feed	10^8 cells g^{-1} feed for 14 d	*O. mykiss*	Effective – there was no mortality of treated fish	Pieters *et al*. (2008)
Aquahumin				
See entry for humic acid (10% solution)				
Ascorbate-2-phosphate (vitamin C)				
In vivo – In-feed	5000 mg kg^{-1} feed for 9 d	*O. mykiss*	Partially effective but 2–16% of medicated fish died	Wahli *et al*. (1985)
	50 mg 200 kg^{-1} feed	*O. mykiss*	Partially effective – reduction in trophont numbers but no details	Wahli *et al*. (1995)
	50 mg 2000 kg^{-1} feed		Partially effective – reduction in trophont numbers but no details	
	1–3 g kg^{-1} feed for 1 week–1 month	Not specified	Effective – no detail	Rahkonen and Koski (2002)
Ascorbate-2-phosphate (Vitamin C) + d-l-alpha-tocopheryl acetate (Vitamin E) complex diet				
In vivo – In-feed for 7 weeks				
	0 + 1·8 mg kg^{-1} feed	*O. mykiss*	Not effective – 44% of medicated fish died	Walhi *et al*. (1998)
	4·3 + 771·0 mg kg^{-1} feed		'Effective' but ~20% of medicated fish died	
	24·8 + 34·0 mg kg^{-1} feed		Not effective – 62% of medicated fish died	
	27·5 + 776·0 mg kg^{-1} feed		'Effective' but ~20% of medicated fish died	
	2065·0 + 2·5 mg kg^{-1} feed		'Effective' but <20% of medicated fish died	
	2093·3 + 30·8 mg kg^{-1} feed		'Effective' but ~20% of medicated fish died	
	2025·0 + 754·3 mg kg^{-1} feed		'Effective' but <20% of medicated fish died	

Table 1. (*Cont.*)

Compound	Dose	Host/parasite stage	Efficacy	Reference
Ascorbyl phosphate				
In vivo – In-feed	50 mg 2000 kg^{-1} feed	*O. mykiss*	Partially effective – reduction in trophont numbers but no details	Wahli *et al*. (1995)
Baycox				
See entry for toltrazuril				
Bithionol				
In vivo – In feed	40 g kg^{-1} of feed for 10 d	*O. mykiss*	Not effective – 68% fish with high number of trophonts	Tojo-Rodriguez and Santamarina-Fernandez (2001)
Bronopol (2-bromo-2-nitropropane-1, 3-diol)				
In vitro	20 mg l^{-1} for 30 min	Protomonts	Partially effective – 76·2% mortality	Shinn *et al*. (in press)
	50 mg l^{-1} for 30 min		Effective – 97·2% mortality	
	100 mg l^{-1} for 30 min		Effective – 100% mortality	
	20 mg l^{-1} for 30 min	Tomocysts	Not effective – 3·3% mortality; tomocyst development delayed	Shinn *et al*. (in press)
	50 mg l^{-1} for 30 min		Not effective – 10% mortality; tomocyst development delayed	
	0·1 mg l^{-1} for 12 h	Theronts	Not effective – 7·15% mortality	Shinn *et al*. (in press)
	0·1 mg l^{-1} for 24 h		Not effective – 31·55% mortality	
	0·1 mg l^{-1} for 36 h		Not effective – 31·66% mortality	
	0·1 mg l^{-1} for 48 h		Not effective – 18% mortality	
	0·25 mg l^{-1} for 12 h		Not effective – 14·03% mortality	
	0·25 mg l^{-1} for 24 h		Not effective – 30·95% mortality	
	0·25 mg l^{-1} for 36 h		Not effective – 40·0% mortality	
	0·25 mg l^{-1} for 48 h		Not effective – 34·84% mortality	
	0·5 mg l^{-1} for 12 h		Not effective – 22·38% mortality	
	0·5 mg l^{-1} for 24 h		Not effective – 38·77% mortality	
	0·5 mg l^{-1} for 36 h		Not effective – 26·51% mortality	
	0·5 mg l^{-1} for 48 h		Partially effective – 59·21% mortality	
	0·75 mg l^{-1} for 12 h		Not effective – 8·88% mortality	
	0·75 mg l^{-1} for 24 h		Not effective – 40·0% mortality	
	0·75 mg l^{-1} for 36 h		Not effective – 26·51% mortality	
	0·75 mg l^{-1} for 48 h		Partially effective – 68·57% mortality	
	1 mg l^{-1} for 12 h		Not effective – 13·88% mortality	
	1 mg l^{-1} for 24 h		Not effective – 37·93% mortality	
	1 mg l^{-1} for 36 h		Not effective – 44·44% mortality	
	1 mg l^{-1} for 48 h		Partially effective – 75·0% mortality	
	1 mg l^{-1} for 12 h		Partially effective – 70·84% mortality	
	1 mg l^{-1} for 24 h		Effective – 100% mortality	
	20 mg l^{-1} for 30 min		Not effective – 18·5% mortality	Shinn *et al*. (in press)

	0 mg l^{-1} for 30 min		Not effective – 31·3% mortality	
	100 mg l^{-1} for 30 min		Partially effective – 51·7% mortality	
	100 mg l^{-1} for 30 min		Effective – 50% mortality; all dead after 43 h	Shinn *et al*. (in press)
In vivo – bath	1 mg l^{-1} for 36 d p.i	*O. mykiss*	Not effective – number of trophonts increased on treated groups	Picón-Camacho *et al*. (in press *a*)
	2 mg l^{-1} for 36 d p.i		Effective – 46% reduction in trophont numbers on the 2nd wave of infection; 83% reduction in trophonts numbers on 3rd wave	
	2 mg l^{-1} 24 h prior inf. and 72 h p.i.		Partially effective – 35–48% trophont reduction on treated groups of infection; 97% reduction in trophont numbers on 3rd wave	
	5 mg l^{-1} for 36 d p.i		Effective – 83% reduction in trophont numbers on the 2nd wave	
	50 mg l^{-1} daily for 1 h for 10 d	*O. mykiss*	Not effective – no reduction in trophont numbers on treated fish	Shinn *et al*. (2003*a*)
	50 mg l^{-1} for 30 min for 10 d (alternate days)	*O. mykiss*	Not effective – no significant reduction in trophont numbers	Shinn *et al*. (unpublished)
	100 mg l^{-1} daily for 30 min for 10 d		Not effective – 33·3% reduction in trophont numbers	Shinn *et al*. (2003*a*)
	100 mg l^{-1} daily for 30 min for 10 d		Effective – 81·1% reduction in trophont numbers	
	100 mg l^{-1} for 1 h on day 7		Not effective – no reduction in trophont numbers on treated fish	
Brochothrix thermosphacta				
In vivo – In-feed	10^{10} cells g^{-1} feed for 14 d	*O. mykiss*	Not effective – 98% mortality on treated fish	Pieters *et al*. (2008)
Cadmium chloride				
In vitro	0·005 ppm for 18–22 h	Theronts	Not effective – 0% mortality	Bisharyan *et al*. (2003)
	0·05 ppm for 10 min, 1 and 5 h		Not effective – 0% mortality	
	0·05 ppm for 18–22 h		Effective – 50–90% mortality	
	0·5 ppm for 10 min and1 h		Not effective – 0% mortality	
	0·5 ppm for 5 h		Effective – 50–90% mortality	
	0·5 ppm for 18–22 h		Effective – 100% mortality	
	5 ppm for 10 min		Not effective – reduction in swimming velocity	
	5 ppm for 1 h		Effective – 50–90% mortality	
	5 ppm for 5 h		Effective – 100% mortality	
	50 ppm for 10 min		Not effective – reduction in swimming velocity	
	50 ppm for 1 h		Effective – 100% mortality	
	500 ppm for 10 min		Effective – 100% mortality	
Carica papaya (papaya)				
In vitro	100 mg l^{-1} for 3 h	Trophonts*	Not effective – 0% mortality	Ekamen *et al*. (2004)
	100 mg l^{-1} for 6 h		Not effective – 10% mortality	
	150 mg l^{-1} for 3 h		Not effective – 5% mortality	
	150 mg l^{-1} for 6 h		Partially effective – 55% mortality	
	200 mg l^{-1} for 3 h		Not effective – 25% mortality	
	200 mg l^{-1} for 6 h		Effective – 100% mortality	
	250 mg l^{-1} for 3 h		Effective – 90% mortality	

Table 1. (*Cont.*)

Compound	Dose	Host/parasite stage	Efficacy	Reference
	250 mg l^{-1} for 6 h		Effective – 100% mortality	
In vivo – bath	200 mg l^{-1} for 92 h	*Carassius a. auratus*	Effective – 89% reduction in trophont number on the skin and fins	Ekamen *et al*. (2004)
	250 mg l^{-1} for 92 h		Effective – 92% reduction in trophont number on the skin and fins	
Chloramine-T (sodium p-toluenesulfonchloramide)				
In vitro	5 mg l^{-1} for 1 h	Protomonts	Effective – 100% mortality	Shinn *et al*. (2001)
	50 mg l^{-1} for 15 min	Theronts	Effective – 100% mortality	
In vivo – bath	1 mg l^{-1} daily for 11 d	*I. punctatus*	Not effective – 100% mortality on treated fish	Tieman and Goodwin (2001)
	2 mg l^{-1} daily for 11 d		Not effective – 100% mortality on treated fish	
	5 mg l^{-1} daily for 11 d		Not effective – 100% mortality on treated fish	
	5, 10 and 15 mg l^{-1} for 1 h	*O. mykiss* *S. fontinalis* *S. trutta*	Not effective – no details	Balta *et al*. (2008)
	10 mg l^{-1} for 6 h	*O. mykiss*	Not effective – no reduction in trophont numbers	Shinn *et al*. (unpublished)
	14 mg l^{-1} 3 times a week for 3 weeks	*Salmo salar*	Not effective – parasite numbers increased over infection period	Rintamäki-Kinnunen *et al*. (2005*a*)
	16 mg l^{-1} 3 times a week for 2 weeks		Trial inconclusive – low parasite numbers across all groups	Rintamäki-Kinnunen *et al*. (2005*a*)
	100 mg l^{-1} for 30 min daily over 10 d period	*O. mykiss*	Effective – 93% reduction in trophont numbers	Shinn *et al*. (2001)
	100 mg l^{-1} for 1 h on day 7 p.i.	*O. mykiss*	Not effective – 14% reduction in trophont numbers	Shinn *et al*. (2003*a*)
	100 mg l^{-1} for 6 h on day 7 p.i.		Not effective – no reduction in trophont numbers	
	100 mg l^{-1} daily for 30 min for 10 d		Effective – 90·5% reduction in trophont numbers	
	100 mg l^{-1} daily for 30 min for 10 d		Effective – 97·3% reduction in trophont numbers	
	100 mg l^{-1} for 30 min 4 times over 10 d		Partially effective – significant reduction in 50% of the tanks	Rahkonen and Koski (2002)
Chloramine-T (sodium p-toluenesulfonchloramide) + formaldehyde				
In vivo – bath	10 + 100 mg l^{-1} 3 times a week for 4 weeks	*S. salar*	Not effective – no details	Rintamäki-Kinnunen *et al*. (2005*a*)
	8 + 125 mg l^{-1} 3 times a week for 5 weeks		Effective – no details	Rintamäki-Kinnunen *et al*. (2005*b*)
Chloramphenicol (D (-) threo-2,2-dichloro-N-[hydroxy-α(hydroxymethyl)-p-nitrophenethyl] acetamide)				
In vitro	100 mg l^{-1} for 3 h	Theronts	Not effective – no details	Wahli *et al*. (1993)
	100 mg l^{-1} for 24 h	Adults**	Not effective – no details	
	100 mg l^{-1} for 24 h	Tomocysts	Not effective – no details	

Chloroquine				
In vitro	200 mg l^{-1} for 2 h	Protomonts	Partially effective – 50% mortality after 2 h. Protomonts surviving develop normally	Tojo-Rodriguez *et al*. (1994)
In vivo – bath	200 mg l^{-1} for 3 h	*O. mykiss*	Not effective – all trophonts developed normally	Tojo-Rodriguez *et al*. (1994)
In-feed	1000 mg kg^{-1} feed for 8 d		Not effective – all trophonts developed normally	
	40 g kg^{-1} feed for 10 d	*O. mykiss*	Not effective – high numbers of trophonts on all treated fish	Tojo-Rodriguez and Santamarina-Fernandez (2001)
Chlortetracycline				
In vitro	100 mg l^{-1} for 24 h	Adults**	Effective – 100% mortality after 1 h	Wahli *et al*. (1993)
	100 mg l^{-1} for 3 h	Theronts	Effective – 100% mortality after 5 min	
	100 mg l^{-1} for 24 h	Tomocysts	Effective – 100% mortality after 24 h	
In vivo – bath	100 mg l^{-1} – 2× for 1 h 1st: day 9 p.i, 2nd: day 12 p.i	*O. mykiss*	Not effective – no details	Wahli *et al*. (1993)
In-feed	75 mg kg^{-1} fish for 10 d		Not effective – no details	
Citrocide				
In vivo – In-feed	10 mg kg^{-1} feed for 7 d p.i.	*O. mykiss*	Not effective ~40% reduction in trophont numbers	Shinn *et al*. (2005)
Citrox BC				
In vivo – In-feed	10 mg kg^{-1} feed for 7 d p.i.	*O. mykiss*	Not effective – 25% reduction in trophont numbers	Shinn *et al*. (2005)
Clopidol (3,5-dichloro-2,6-dimethyl-4-pyridinol) commercialised as Coyden				
In vivo – In-feed	65 mg kg^{-1} feed for 10 d prior inf.	*O. mykiss*	Not effective – 35·2% reduction in trophont numbers	Shinn *et al*. (2003*a*)
	92 mg kg^{-1} feed for 10 d prior inf.		Not effective – 20·1% reduction in trophont numbers	
	72 mg kg^{-1} feed for 10 d prior inf.		Not effective – 35·6% reduction in trophont numbers	Shinn *et al*. (unpublished)
Copper sulphate ($CuSO_4$)				
In vitro	55 μg l^{-1} for 24 h	Tomites	Not effective – 100% manage to infect *C. auratus*	Ling *et al*. (1993)
	110 μg l^{-1} for 24 h		Not effective – 90% manage to infect *C. auratus*	
	160 μg l^{-1} for 24 h		Effective – tomites inactive but 20% manage to infect *C. auratus*	
	255 μg l^{-1} for 24 h		Effective – 100% mortality	
	220 μg l^{-1} for 24 h		Effective – 100% mortality	
	0·027 mg Cu l^{-1} as $CuSO_4$ for 3 h (alkalinity 48 mg l^{-1})	Theronts	Partially effective – 50% mortality	Goodwin and Straus (2006)
	0·028 mg nonchelated liquid $CuSO_4$ l^{-1} for 3 h (alkalinity 48 mg l^{-1})		Partially effective – 50% mortality	
	0·027 mg Cu l^{-1} as $CuSO_4$ for 3 h (alkalinity 48 mg l^{-1})		Partially effective – 50% mortality	
	0·05 mg Cu l^{-1} as $CuSO_4$ for 3 h (alkalinity 48 mg l^{-1})		Effective – 95% mortality	
	0·05 mg nonchelated liquid $CuSO_4$ l^{-1} for 2 h (alkalinity 48 mg l^{-1})		Effective – 95% mortality	

Table 1. (*Cont.*)

Compound	Dose	Host/parasite stage	Efficacy	Reference
	0·056 Cu l^{-1} as $CuSO_4$ for 3 h (alkalinity 243 mg l^{-1})		Partially effective – 50% mortality	
	0·053 mg nonchelated liquid $CuSO_4$ l^{-1} for 3 h (alkalinity 243 mg l^{-1})		Partially effective – 50% mortality	
	0·075 mg Cu l^{-1} as $CuSO_4$ for 3 h (alkalinity 243 mg l^{-1})		Effective – ~ 95% mortality	
	0·075 mg nonchelated liquid $CuSO_4$ l^{-1} for 3 h (alkalinity 243 mg l^{-1})		Effective – ~ 95% mortality	
	< 0·25 mg l^{-1} Cu l^{-1} as $CuSO_4$ or nonchelated liquid $CuSO_4$ l^{-1} up to 1 h (alkalinity 48 and 243 mg l^{-1})		Not effective – no reduction in theront survival	
In vivo – bath	0·05 mg l^{-1} for 10 d	*I. punctatus*	Not effective – 100% of infected fish died on day 10	Schlenk *et al*. (1998)
	0·05 mg l^{-1} daily for 17 d	*B. bidyanus*	Not effective – treated fish remained infected	Rowland *et al*. (2009)
	0·1 mg l^{-1} for 10 d	*I. punctatus*	Effective – no trophonts found on treated fish	Schlenk *et al*. (1998)
	0·1 mg l^{-1} for 8 d		Not effective – all treated fish died on day 13	
	0·1 mg l^{-1} daily for 17 d	*B. bidyanus*	Effective – treated fish free of trophonts	Rowland *et al*. (2009)
	0·20 mg l^{-1} daily for 14 d		Effective – treated fish free of trophonts	
	0·25 mg l^{-1} daily for 14 d		Effective – treated fish free of trophonts	
	255 μg Cu^{+2} l^{-1} for 1 week	*C. auratus*	'Effective' but 11·1% of infected fish died	Ling *et al*. (1993)
	255 μg Cu^{+2} l^{-1} for 2 weeks		'Effective' but 33·3% of infected fish died	
	255 μg Cu^{+2} l^{-1} for 3 weeks		Not effective – 44·4% of infected fish died	
	288 μg Cu^{+2} l^{-1} for 15 min		Not effective – 100% of infected fish died	
	288 μg Cu^{+2} l^{-1} for 30 min		Not effective – 66·70% of infected fish died	
	288 μg Cu^{+2} l^{-1} for 60 min		Not effective – 44·4% of infected fish died	
	288 μg Cu^{+2} l^{-1} for 2 h		'Effective' but 11·1% of infected fish died	
	0·4 mg l^{-1} for 8 d	*I. punctatus*	Effective – no trophonts found on treated fish	Schlenk *et al*. (1998)
	0·5 mg l^{-1} for 10 d		Effective – no trophonts found on treated fish	
	0·5 mg l^{-1} daily for 17 d	*B. bidyanus*	Not effective – 100% of infected fish died†	Rowland *et al*. (2009)
	0·8 mg l^{-1} for 8 d	*I. punctatus*	Effective – no trophonts found on treated fish	Schlenk *et al*. (1998)
	1 mg l^{-1} for 10 d		Effective – no trophonts found on treated fish	
	1 mg l^{-1} daily for 17 d	*B. bidyanus*	Not effective – 100% of infected fish died†	Rowland *et al*. (2009)
(static tanks)	1 mg l^{-1} daily for 11 d (alkalinity 68 mg l^{-1})	*I. punctatus*	Not effective – 80–100% of the treated infected fish died	Tieman and Goodwin (2001)
	1 mg l^{-1} daily for 11 d (alkalinity 180 and 250 mg l^{-1})		Not effective – 80% of the treated infected fish died	
	1 mg l^{-1} alternate day for 11 d (alkalinity 150 mg l^{-1})		Not effective – all the treated infected fish died	
	1·1 mg l^{-1} (8 d trial) Treatment: d1, 3, 5 and 7	*I. punctatus*	'Effective' – 15% of the treated infected fish died	Straus (2008)
	1·2 mg l^{-1} for 8 d	*I. punctatus*	Effective – no trophonts found on treated fish	Schlenk *et al*. (1998)
	1·5 mg l^{-1} for 10 d	*I. punctatus*	Effective – no trophonts found on treated fish	

(static tanks)	1·5 mg l^{-1} daily for 11 d (alkalinity 68 mg l^{-1})	*I. punctatus*	Not effective – 40% of the treated infected fish died (treated fish remain infected)	Tieman and Goodwin (2001)
	1·5 mg l^{-1} daily for 11 d (alkalinity 180 and 250 mg l^{-1})		Not effective – all the treated infected fish died	
	1·5 mg l^{-1} alternate day for 11 d (alkalinity 50 mg l^{-1})		Not effective – all the treated infected fish died	
	1·6 mg l^{-1} for 8 d	*I. punctatus*	Effective – no trophonts found on treated fish	Schlenk *et al*. (1998)
	2·0 mg l^{-1} for 10 d	*I. punctatus*	Effective – no trophonts found on treated fish	Schlenk *et al*. (1998)
	2·2 mg l^{-1} (8 d trial) Treatment: d1, 3, 5 and 7	*I. punctatus*	Not effective – 81·7% of the treated infected fish died	Straus (2008)
	3·3 mg l^{-1} (8 d trial) Treatment: d1, 3, 5 and 7		Not effective – 98·3% of the treated infected fish died	
	4·4 mg l^{-1} (8 d trial) Treatment: d1, 3, 5 and 7		Not effective – 96·7% of the treated infected fish died	
Coyden				
See entry clopidol (3, 5-dichloro-2, 6-dimethyl-4-pyridinol)				
Decoquinate				
In vivo – In-feed	100 mg kg^{-1} feed 10 d prior to infection	*O. mykiss*	Not effective – no reduction in trophont numbers on treated fish	Shinn *et al*. (2003*a*)
Desirox				
See entry for peracetic acid + acetic acid + hydrogen peroxide based formulations (13% PAA + 20% AA + 20% H_2O_2)				
Detarox				
See entry for peracetic acid + acetic acid + hydrogen peroxide based formulations				
Diethylcarbamazine				
In vivo – In-feed	40 g kg^{-1} feed for 10 d	*O. mykiss*	Partially effective – lower trophont counts observed in skin scrapes (60% of treated fish free of infection)	Tojo-Rodriguez and Santamarina-Fernandez (2001)
Dimetridazole (DMZ)				
In vitro	5 mg l^{-1} for 3 h	Theronts	Not effective – no details	Wahli *et al*. (1993)
	5 mg l^{-1} for 24 h	Adults**	Not effective – no details	
	5 mg l^{-1} for 24 h	Tomocysts	Not effective – no details	
In vivo – bath	28 mg/feed mixed with lactate (Emetryl ®) for 10 d	*O. mykiss*	Effective – no visible signs of infection by day 7 p.i.	Rapp (1995)
In-feed	40 g kg^{-1} feed for 10 d	*O. mykiss*	Not effective – 85% of treated fish have high numbers of trophonts	Tojo-Rodriguez and Santamarina-Fernandez (2001)
Diminazine aceturate				
In vitro	100 mg l^{-1} for 2 h	Protomonts	Partially effective – 75% mortality after 2 h	Tojo-Rodriguez *et al*. (1994)
	200 mg l^{-1} for 2 h		Effective – 100% mortality after 45 min	
In vivo – bath	100 mg l^{-1} for 3 h	*O. mykiss*	Not effective – all protomonts developed normally	Tojo-Rodriguez *et al*. (1994)

Table 1. (*Cont.*)

Compound	Dose	Host/parasite stage	Efficacy	Reference
In-feed	1000 mg kg^{-1} feed for 8 d		Not effective – all protomonts developed normally	
Elancoban				
See entry for monensin sodium				
Emetryl ®				
See entry for dimetrazole				
Enheptin (2-amino-5-nitrothiazole) diluted in ethyl alcohol and acetone				
In vitro	100 mg l^{-1} for 2 min	Trophozoites*	Effective – 100% mortality after 2 h post exposure	Post and Vesley (1983)
Formaldehyde				
In vitro	10 μl l^{-1} for 10 h	Trophonts*	Not effective – 7% mortality	Lahnsteiner and Weismann (2007)
	45 μl l^{-1} for 10 h		Effective – 7% mortality, no viable theronts produced	
	55 μl l^{-1} for 10 h		Effective – 100% mortality	
	25 mg l^{-1} for 24 h	Adults**	Effective – 100% mortality after 24 h	Wahli *et al*. (1993)
	32 mg l^{-1} for <2 h 30 min	Protomonts	Effective – 100% mortality	Heinecke and Buchmann (2009)
	64 mg l^{-1} for <1 h		Effective – 100% mortality	
	100 mg l^{-1} for 24 h	Adults**	Effective – 100% mortality after 1 h	Wahli *et al*. (1993)
	128 mg l^{-1} for <15 min	Protomonts	Effective – 100% mortality	Heinecke and Buchmann (2009)
	25 mg l^{-1} for 24 h	Tomocysts	Effective – 100% mortality after 24 h	Wahli *et al*. (1993)
	100 mg l^{-1} for 24 h		Effective – 100% mortality after 24 h	
	8 mg l^{-1} for 2 h 30 min (21–22 °C)	Theronts	Effective – 100% mortality	Heinecke and Buchmann (2009)
	8 mg l^{-1} for 5 h (11–12 °C)		Effective – 100% mortality	
	10 mg l^{-1} for 1 h		Not effective – ~ 5% mortality	Shinn *et al*. (2005)
	16 mg l^{-1} for ~2 h (11–12 °C)		Effective – 100% mortality	Heinecke and Buchmann (2009)
	16 mg l^{-1} for ~1 h 5 min (21–22 °C)		Effective – 100% mortality	
	25 mg l^{-1} for 3 h		Effective – 100% mortality after 30 min	Wahli *et al*. (1993)
	32 mg l^{-1} for ~1 h 5 min (11–12 °C)		Effective – 100% mortality	Heinecke and Buchmann (2009)
	32 mg l^{-1} for ~ < 50 min (21–22 °C)		Effective – 100% mortality	
	50 mg l^{-1} for 1 h		Not effective – ~ 10% mortality	Shinn *et al*. (2005)
	64 mg l^{-1} for <50 min (11–12 °C)		Effective – 100% mortality	Heinecke and Buchmann (2009)
	64 mg l^{-1} for 15 min (21–22 °C)		Effective – 100% mortality	
	100 mg l^{-1} for 1 h		Not effective – ~ 3% mortality	Shinn *et al*. (2005)
	100 mg l^{-1} for 3 h		Effective – 100% mortality after 30 min	Wahli *et al*. (1993)

	200 mg l^{-1} for 1 h		Not effective – ~ 40% mortality	Shinn *et al*. (2005)
In vivo – bath	10 μl l^{-1} for 6 h for 5 d (18 °C, 24 h intervals)	*O. mykiss*	Not effective – 0% survival of treated fish on d1 and 3	Lahnsteiner and Weismann (2007)
	40 μl l^{-1} for 4 h for 5 d (18 °C, 24 h intervals)		Not effective – 30% survival of treated fish on d1; 0% survival on d 3	
	80 μl l^{-1} for 1 h for 5 d (18 °C, 24 h intervals)		Effective – 50% survival on treated fish on d1 and 3; no trophonts seen on fish on d1 and 3	
	80 μl l^{-1} for 2 h for 5 d	*C. carpio*	Effective – all treated fish survived; low number of trophonts on d1 and 3	Lahnsteiner and Weismann (2007)
	110 μl l^{-1} for 2 h for 5 d		Effective – all treated fish survived; no trophonts on d1 and 3	
	110 μl l^{-1} for 1 h for 5 d (18 °C, 24 h intervals)	*O. mykiss*	Effective – 90% survival of treated fish on d1 and 3; no trophonts on d1 and 3	
	110 μl l^{-1} for 1 h for 5 d (10 °C, 48 h intervals)		Effective – 100% survival of treated fish on d1 and 3; no trophonts on d1 and 3	Lahnsteiner and Weismann (2007)
	110 μl l^{-1} for 1 h for 5 d (18 °C, 24 h intervals)		Effective – 100% survival of treated fish on d1 and 3; no trophonts on d1 and 3	
	110 μl l^{-1} for 1 h for 5 d (18 °C, 48 h intervals)		Not effective – 50% and 10% survival of treated fish on d1 and 3; heavy infections on d1 and 3	
	110 μl l^{-1} for 1 h for 5 d (25 °C, 24 h intervals)		Not effective – 0% survival of treated fish on d1 and 3; heavy infections on d1 and 3	
	110 μl l^{-1} for 12 h (25 °C)	*O. mykiss*	Not effective – 100% and 10% survival of treated fish on d1 and 3; moderate and heavy infections on d1 and 3	
	110 μl l^{-1} for 3 × 1 h for 5 d (25 °C, 24 h intervals)		Not effective – 70% and 0% survival of treated fish on d1 and 3; Moderate infection on d1	
	110 μl l^{-1} for 5 × 1 h for 5 d (25 °C, 24 h intervals)		Not effective – 30% and 0% survival of treated fish on d1and 3; moderate infection on d1	
	110 μl l^{-1} for 7 × 1 h for 5 d (25 °C, 24 h intervals)		Not effective – 0% and 0% survival of treated fish on d1 and 3; heavy infection on d1	
	110 μl l^{-1} for 12 h (18 °C)		Not effective – 100% and 10% survival of treated fish on d1 and 3 medium and very heavy infections on d1 and 3	
	110 μl l^{-1} for 3 × 1 h for 5 d (18 °C, 24 h intervals)		Not effective – 100% and 40% survival of treated fish on d1 and 3; low and heavy infections on d1 and 3	
	110 μl l^{-1} for 5 × 1 h for 5 d (18 °C, 24 h intervals)		Effective – 100% survival of treated fish on d1 and 3; no infection on d1 and 3	
	110 μl l^{-1} for 7 × 1 h for 5 d (18 °C, 24 h intervals)		Effective – 100% survival of treated fish on d1 and 3; no infection on d1 and 3	
	0·1, 0·15 and 0·2 ml l^{-1} for 1 h	*O. mykiss* *S. fontinalis* *S. trutta*	Effective – reduction in the number of trophonts on treated fish	Balta *et al*. (2008)

Table 1. (*Cont.*)

Compound	Dose	Host/parasite stage	Efficacy	Reference
	10 mg l^{-1} for 17 d	*B. bidyanus*	Not effective – all treated infected fish died	Rowland *et al.* (2009)
	20 mg l^{-1} for 17 d		Not effective – all treated fish still infected	
	25 mg l^{-1} – 2× for 1 h	*O. mykiss*	Not effective – not specified but fish survival compromised	Wahli *et al.* (1993)
	1st: day 9 p.i, 2nd: day 12 p.i			
	25 mg l^{-1} for 4 h for 4 d week $^{-1}$	*I. punctatus*	Not effective – 40–70% of treated infected fish died	Bodensteiner *et al.* (2000)
(static tanks)	25 mg l^{-1} alternate days for 20 d	*I. punctatus*	Not effective – all treated infected fish died	Tieman and Goodwin (2001)
	25 mg l^{-1} daily for 20 d		Partially effective – 20–60% of treated infected fish died	
	25 mg l^{-1} 3–4 times a week for 6 weeks	*S. salar*	Not effective – parasite load increased on treated fish	Rintamäki-Kinnunen *et al.* (2005*b*)
	25 mg l^{-1} 3–4 times a week for 6 weeks	*S. trutta*	Not effective – parasite load increased on treated fish	Rintamäki-Kinnunen *et al.* (2005*b*)
	30 mg l^{-1} for 17 d	*B. bidyanus*	Effective – no trophonts found on treated fish	Rowland *et al.* (2009)
	50 mg l^{-1} alternate day for 20 d	*I. punctatus*	Not effective – all treated infected fish died	Tieman and Goodwin (2001)
	50 mg l^{-1} daily for 20 d		Partially effective – 20–60% of treated infected fish died	
	50 mg l^{-1} 3–4 times a week for 6 weeks	*S. salar*	Not effective – parasite load increased on treated fish	Rintamäki-Kinnunen *et al.* (2005*b*)
	50 mg l^{-1} 3–4 times a week	*S. trutta*	Not effective – parasite load increased on treated fish	
	100 mg l^{-1} – 2× for 1 h	*O. mykiss*	Not effective – not specified but fish survival compromised	Wahli *et al.* (1993)
	1st: day 9 p.i, 2nd: day 12 p.i			
(static tanks)	100 mg l^{-1} daily for 20 d	*I. punctatus*	Not effective – all treated infected fish died	Tieman and Goodwin (2001)
(flow through)	100 mg l^{-1} alternate day for 20 d		Not effective – all treated infected fish died †	
	60 – 250 mg l^{-1} for 20 min- 1 h	Not specified	'Effective' – efficacy though not specified	Rahkonen and Koski (2002)
Formaldehyde + Desirox (13% peracetic acid, 20% acetic acid and 20% hydrogen peroxide)				
In vivo – bath	25 + 10 mg l^{-1} 3–4 times a for 4 weeks week	*S. salar*	'Effective' – parasite load reduced on treated fish	Rintamäki-Kinnunen *et al.* (2005*b*)
	50 + 10 mg l^{-1} 3–4 times a week for 4 weeks		'Effective' – parasite load reduced on treated fish	
	100 + 10 mg l^{-1} 3 times a week for 4 weeks	*S. salar*	Trial inconclusive – details missing	Rintamäki-Kinnunen *et al.* (2005*a*)
	123 + 8 mg l^{-1} 4 times a week for 5 weeks		Not effective – parasite load increased on treated fish	Rintamäki-Kinnunen *et al.* (2005*a*)

Formaldehyde + hydrogen peroxide				
In vivo – bath	100 + 100 mg l^{-1} 3 times a week for 3 weeks		Trial inconclusive – details missing	Rintamäki-Kinnunen *et al*. (2005*a*)
Formaldehyde + malachite green				
In vitro	25 + 0·1 mg l^{-1} for 24 h	Adults**	Effective – 100% mortality after 24 h	Wahli *et al*. (1993)
	100 + 0·4 mg l^{-1} for 24 h		Effective – 100% mortality after 24 h	
	25 + 0·1 mg l^{-1} for 24 h	Tomocysts	Effective – 100% mortality after 24 h	
	100 + 0·4 mg l^{-1} for 24 h		Effective – 100% mortality after 24 h	
	25 + 0·1 mg l^{-1} for 3 h	Theronts	Effective – 100% mortality after 30 min	
	100 + 0·4 mg l^{-1} for 3 h		Effective – 100% mortality after 5 min	
In vivo – bath	25 + 0·05 mg l^{-1}	*Cichla ocellaris*	'Effective' – efficacy not specified	Guest (1983)
	25 + 0·1 mg l^{-1} – 2× for 1 h	*O. mykiss*	Partially effective against the parasites – efficacy not specified	Wahli *et al*. (1993)
	1st: day 9 p.i, 2nd: day 12 p.i			
	100 + 0·4 mg l^{-1} – 2× for 1 h		Partially effective against the parasites – efficacy not specified	
	1st: day 9 p.i, 2nd: day 12 p.i			
	225 + 0·83 mg l^{-1} for 3 times a week *S. salar* for 3 weeks		Partially effective – small increases in parasite burdens observed over infection period	Rintamäki-Kinnunen *et al*. (2005*a*)
	225 + 0·83 mg l^{-1} for 3 times a week for 2 weeks		Trial inconclusive – low parasite numbers across all groups	
Furacin ([(5-nitrofuran-2-yl) methylideneamino] urea)				
In vitro	100 mg l^{-1} for 2 min	Trophozoites*	Effective – 30% mortality after 12 h, 80% after 24 h post exposure	Post and Vesley (1983)
Furazolidone (mixed with ethanol)				
In vitro	100 mg l^{-1} for 24 h	Adults**	Not effective – no details	Wahli *et al*. (1993)
	100 mg l^{-1} for 24 h	Tomocysts	Effective – 100% mortality after 24 h	
	100 mg l^{-1} for 3 h	Theronts	Not effective – no details	
In vivo – bath	25 mg l^{-1} – 2× for 1 h	*O. mykiss*	Not effective – no details	Wahli *et al*. (1993)
	1st: day 9 p.i, 2nd: day 12 p.i			
In-feed	50 mg kg^{-1} fish for 10 d		Not effective – no details	
Furoxone (3-[(5-nitrofuran-2-yl) methylideneamino]-1,3-oxazolidin-2-one) diluted in ethyl alcohol and acetone				
In vitro	100 mg l^{-1} for 2 min	Trophozoites*	Not effective – 0% mortality after 24 h post exposure	Post and Vesley (1983)
β-Glucan (from *Saccharomyces cerevisiae*)				
In vivo – In-feed	0·2% for 14 d prior inf.	*O. mykiss*	Not effective – 14% trophont reduction	Lauridsen and Buchmann (2010)
	0·2% for 35 d prior inf.		Not effective – 18% trophont reduction	
HbβP-1 (peptide from the β-haemoglobin peptide family)				
In vitro	12·5 μg ml^{-1} for 5 min 21 s	Trophonts*(323 μm)	Effective – 100% mortality	Ullal and Noga (2010)
	12·5 μg ml^{-1} for 1 min 35 s	(222 μm)	Effective – 100% mortality	
	12·5 μg ml^{-1} for 2 min 50 s	(500 μm)	Effective – 100% mortality	
	25 μg ml^{-1} for 6 min 36 s	(323 μm)	Effective – 100% mortality	
	25 μg ml^{-1} for 1 min 54 s	(231 μm)	Effective – 100% mortality	
	25 μg ml^{-1} for 4 min 14 s	(519 μm)	Effective – 100% mortality	

Table 1. (*Cont.*)

Compound	Dose	Host/parasite stage	Efficacy	Reference
	50 μg ml^{-1} for 4 min 3 s	(323 μm)	Effective – 100% mortality	
	100 μg ml^{-1} for 3 min 18 s	(323 μm)	Effective – 100% mortality	
	200 μg ml^{-1} for 3 min 15 s	(323 μm)	Effective – 100% mortality	
Humic acid (10% solution) commercially sold as Aquahumin				
In vitro	50 μl l^{-1} for 10 h	Trophonts*	Not effective – 10% mortality	Lahnsteiner and Weismann (2007)
	100 μl l^{-1} for 10 h		Partially effective – 77% mortality	
	150 μl l^{-1} for 10 h		Effective – 90% mortality, no theronts produced by surviving trophonts	
	200 μl l^{-1} for 10 h		Effective – 100% mortality	
In vivo – bath	100 μl l^{-1} for 2 h for 5 d	*O. mykiss*	Effective – 90% survival of treated fish; no infections d1 and 3	Lahnsteiner and Weismann (2007)
(daily for 5 d)	100 μl l^{-1} for 4 h for 5 d	*C. carpio*	Not effective – 100% and 60% survival of treated fish on d1and 3; moderate and heavy infections on d1 and 3	
	150 μl l^{-1} for 2 h for 5 d	*O. mykiss*	Effective – 100% survival of treated fish; no infections d1 and 3	
	150 μl l^{-1} for 4 h for 5 d	*C. carpio*	Not effective – 100% and 70% survival of treated fish on d1and 3; moderate and heavy infections on d1 and 3 on treated fish	
	150 μl l^{-1} for 2 h for 5 d (10 °C, 48 h interval)	*O. mykiss*	Effective – 100% survival of treated fish; no infections d1 and 3	
	150 μl l^{-1} for 2 h for 5 d (18 °C, 24 h interval)		Partially effective – 70% survival of treated fish; no infections d1 and 3	
	150 μl l^{-1} for 2 h for 5 d (18 °C, 48 h interval)		Not effective – 0% survival on treated fish	
	150 μl l^{-1} for 2 h for 5 d (25 °C, 24 h interval)		Not effective – 0% survival of treated fish; heavy infections on d1 and3 on treated fish	
	200 μl l^{-1} for 4 h for 5 d	*C. carpio*	Not effective – 100% and 60% survival of treated fish on d1 and 3; moderate and heavy infections on d1 and 3 on treated fish	
Hydrogen peroxide (H_2O_2)				
In vitro	< 50 mg l^{-1} for 10 h	Trophonts*	Not effective – trophonts developed normally	Lahnsteiner and Weismann (2007)
	10 mg l^{-1} for 1 h	Theronts	Not effective – $\sim$ 10% mortality	Shinn *et al*. (2005)
	50 mg l^{-1} for 1 h		Not effective – $\sim$ 5% mortality	
	100 mg l^{-1} for 1 h		Not effective – $\sim$ 5% mortality	
	200 mg l^{-1} for 1 h		Not effective – $\sim$ 15% mortality; 20% mortality	Shinn *et al*. (unpublished)

In vivo – bath	25 mg l^{-1} daily for 20 d (flow through)	*I. punctatus*	Not effective – 80% of treated infected fish died	Tieman and Goodwin (2001)
	25 mg l^{-1} daily for 20 d (static tanks)		Not effective – all treated infected fish died	
Hydrogen peroxide + acetic acid based formulation commercialized as Perotan				
In vitro	50 μl l^{-1} for 10 h	Trophonts*	Not effective – 7% mortality	Lahnsteiner and Weismann (2007)
	100 μl l^{-1} for 10 h		Effective – 100% mortality	
Incimaxx Aquatic				
See entry for peracetic acid + acetic acid + hydrogen peroxide + peroctanoic acid based formulation				
Iodine				
In vivo – bath	0·25 mg l^{-1} daily for 11 d	*I. punctatus*	Not effective – all treated infected fish died	Tieman and Goodwin (2001)
(static tanks)	0·50 mg l^{-1} daily for 11 d		Not effective – all treated infected fish died	
	1·00 mg l^{-1} daily for 11 d		Not effective – all treated infected fish died	
	1·00 mg l^{-1} for 11 d (alternate days)		Not effective – all treated infected fish died	
Ivermectin commercialised as Ivomec				
In vitro	< 50 mg l^{-1} for 10 h	Trophonts*	Not effective – trophonts developed normally	Lahnsteiner and Weismann (2007)
Ivomec				
See entry for Ivermectin				
Ketoconazole				
In vitro	200 mg l^{-1} for 2 h		Effective – 0% mortality after 2 h but protomonts do not develop	Tojo-Rodriguez *et al*. (1994)
In vivo – bath	200 mg l^{-1} for 3 h	*O. mykiss*	Not effective – all trophonts develop normally	Tojo-Rodriguez *et al*. (1994)
In-feed	1000 mg kg^{-1} feed for 8 d		Not effective – toxic to the fish; all trophonts develop normally	
	40 g kg^{-1} feed for 10 d	*O. mykiss*	Partially effective – 50% of medicated fish with low numbers of trophonts	Tojo-Rodriguez and Santamarina-Fernandez (2001)
Levamisole				
In vivo – In-feed	40 g kg^{-1} feed for 10 d	*O. mykiss*	Not effective – 40% of medicated fish with low numbers of trophonts	Tojo-Rodriguez and Santamarina-Fernandez (2001)
Macleaya cordata (active compound sanguinarine)				
In vitro	60 mg l^{-1} for 4 h	Trophonts*	Not effective – 32·5% mortality	Yao *et al*. (2010)
(Butanol extract)	80 mg l^{-1} for 4 h		Not effective – 47·5% mortality	
	100 mg l^{-1} for 4 h		Partially effective – 65% mortality	
	120 mg l^{-1} for 4 h		Partially effective – 70% mortality	
(Chloroform extract)				
	30 mg l^{-1} for 4 h		Partially effective – 67·5% mortality	
	50 mg l^{-1} for 4 h		Effective – 82·5% mortality	

Table 1. (*Cont.*)

Compound	Dose	Host/parasite stage	Efficacy	Reference
	70 mg l^{-1} for 4 h		Effective – 100% mortality	
	90 mg l^{-1} for 4 h		Effective – 100% mortality	
(Ethyl acetate extract)				
	60 mg l^{-1} for 4 h		Not effective – 37·5% mortality	
	80 mg l^{-1} for 4 h		Partially effective – 52·5% mortality	
	100 mg l^{-1} for 4 h		Effective – 80% mortality	
	120 mg l^{-1} for 4 h		Effective – 80% mortality	
(Petroleum ether extract)				
	60 mg l^{-1} for 4 h		Not effective – 27·5% mortality	
	80 mg l^{-1} for 4 h		Not effective – 30% mortality	
	100 mg l^{-1} for 4 h		Not effective – 30% mortality	
	120 mg l^{-1} for 4 h		Not effective – 40% mortality	
(Water extract)				
	60 mg l^{-1} for 4 h		Not effective – 7·5% mortality	
	80 mg l^{-1} for 4 h		Not effective – 17·5% mortality	
	100 mg l^{-1} for 4 h		Not effective – 25% mortality	
	120 mg l^{-1} for 4 h		Not effective – 27·5% mortality	
(Fractions from the chloroform extract)				
(Fraction A)	10 mg l^{-1} for 4 h	Trophonts*	Not effective – 12·5% mortality	Yao *et al*. (2010)
	20 mg l^{-1} for 4 h		Not effective – 15% mortality	
	30 mg l^{-1} for 4 h		Not effective – 22·5% mortality	
(Fraction B)	10 mg l^{-1} for 4 h		Not effective – 12·5% mortality	
	20 mg l^{-1} for 4 h		Not effective – 20% mortality	
	30 mg l^{-1} for 4 h		Not effective – 25% mortality	
(Fraction C)	10 mg l^{-1} for 4 h		Not effective – 42·5% mortality	
	20 mg l^{-1} for 4 h		Not effective – 67·5% mortality	
	30 mg l^{-1} for 4 h		Not effective – 87·5% mortality	
(Fraction D)	5 mg l^{-1} for 4 h		Effective – 90% mortality	
	9 mg l^{-1} for 4 h		Effective – 100% mortality	
	11 mg l^{-1} for 4 h		Effective – 100% mortality	
(Fraction E)	10 mg l^{-1} for 4 h		Partially effective – 55% mortality	
	20 mg l^{-1} for 4 h		Partially effective – 77·5% mortality	
	30 mg l^{-1} for 4 h		Effective – 92·5% mortality	
(Fraction F)	10 mg l^{-1} for 4 h		Not effective – 7·5% mortality	
	20 mg l^{-1} for 4 h		Not effective – 20% mortality	
	30 mg l^{-1} for 4 h		Not effective – 25% mortality	
(Fraction G)	10 mg l^{-1} for 4 h		Not effective – 5% mortality	
	20 mg l^{-1} for 4 h		Not effective – 7·5% mortality	
	30 mg l^{-1} for 4 h		Not effective – 15% mortality	

(Compounds from Fraction D)				
(Compound I)	5 mg l^{-1} for 4 h	Trophonts*	Not effective – 17·5% mortality	
	7 mg l^{-1} for 4 h		Not effective – 22·5% mortality	
	9 mg l^{-1} for 4 h		Not effective – 22·5% mortality	
(Compound II)	5 mg l^{-1} for 4 h		Not effective – 22·5% mortality	
	7 mg l^{-1} for 4 h		Not effective – 30% mortality	
	9 mg l^{-1} for 4 h		Not effective – 37·5% mortality	
(Compound III)	0·5 mg l^{-1} for 4 h		Effective – 87·5% mortality	
	0·9 mg l^{-1} for 4 h		Effective – 100% mortality	
	1·3 mg l^{-1} for 4 h		Effective – 100% mortality	
(Compound IV)	5 mg l^{-1} for 4 h		Not effective – 5% mortality	
	7 mg l^{-1} for 4 h		Not effective – 7·5% mortality	
	9 mg l^{-1} for 4 h		Not effective – 22·5% mortality	
In vivo – bath				
(Compound I)	0·2 mg l^{-1} for 48 h	*Ctenopharyngodon idella*	Not effective – 16·1% trophont reduction on treated fish	
	0·3 mg l^{-1} for 48 h		Not effective – 17·3% trophont reduction on treated fish	
	0·4 mg l^{-1} for 48 h		Not effective – 32·9% trophont reduction on treated fish	
	0·5 mg l^{-1} for 48 h		Partially effective – 53·9% trophont reduction on treated fish	
	0·6 mg l^{-1} for 48 h		Partially effective – 75·3% trophont reduction on treated fish	
	0·7 mg l^{-1} for 48 h		Effective – 82·3% trophont reduction on treated fish	
	0·8 mg l^{-1} for 48 h		Effective – 89·4% trophont reduction on treated fish	
	0·9 mg l^{-1} for 48 h		Effective – 96·8% trophont reduction on treated fish	
Malachite green				
In vitro	1 mg l^{-1} for 24 h	Adults**	Effective – 100% mortality after 1 h	Wahli *et al*. (1993)
	0·15 mg l^{-1} for 24 h	Tomocysts	Effective – 100% mortality	Buchman *et al*. (2003)
	1 mg l^{-1} for 24 h	Tomocysts	Effective – 100% mortality after 24 h	Wahli *et al*. (1993)
	0·004 mg l^{-1} for 1·5, 3 and 15 h	Theronts	Not effective – < 50% mortality	Buchman *et al*. (2003)
	0·02 mg l^{-1} for 1·5, 3 and 15 h		Not effective – < 50% mortality	
	0·10 mg l^{-1} for 1·5 and 3 h		Not effective – < 50% mortality	
	0·10 mg l^{-1} for 15 h		Partially effective – > 50% mortality	
	1 mg l^{-1} for 3 h		Effective – 100% mortality after 1 h	Wahli *et al*. (1993)
	50 mg l^{-1} for 15 h		Partially effective – > 50% mortality	Buchman *et al*. (2003)
	50 mg l^{-1} for 1·5, 3 and 15 h		Partially effective – > 50% mortality	
In vivo – bath	25 mg l^{-1} – 2× for 1 h 1st: day 9 p.i, 2nd: day 12 p.i	*O. mykiss*	'Effective' – no details	Wahli *et al*. (1993)
	0·1 mg l^{-1} daily for 20 d (static tanks)	*I. punctatus*	'Effective' – no trophonts on treated fish but toxic to fish experiment stopped on d9	Tieman and Goodwin (2001)

Table 1. (*Cont.*)

Compound	Dose	Host/parasite stage	Efficacy	Reference
	0·1 mg l^{-1} daily for 20 d (flow through)		Effective – no trophonts on treated fish; 0% fish mortality	Tieman and Goodwin (2001)
Malachite green (coloured salt)				
In vivo – In-feed	1·2 g kg^{-1} feed for 10 d (fish species with stomach)	*Paracheirodon axelrodi* *Hyphessobrycon herbertaxelrodi* *Hyphessobrycon flammeu* *Hasemania nana* *Aequidens pulcher*	Effective – medicated fish free of trophonts by d 5–8	Ruider *et al*. (1997)
	1·2 g kg^{-1} feed for 10 d (fish species without stomach)	*Xiphophorous helleri* *Barbus tetrazona tetrazona* *Xiphophorus maculates*	Effective – medicated fish free of trophonts by d 7–8	Ruider *et al*. (1997)
Malachite green (carbinolbase)				
In vivo – In-feed	1·2 g kg^{-1} feed for 10 d (fish species with stomach)	*P. axelrodi* *H. herbertaxelrodi* *H. flammeus* *H. nana* *A. pulcher*	Effective – medicated fish free of trophonts by d 6–8	Ruider *et al*. (1997)
	1·2 g kg^{-1} feed for 10 d (fish species without stomach)	*X. helleri* *X. maculates*	Effective – medicated fish free of trophonts by d 6–7	Ruider *et al*. (1997) *B. tetrazona tetrazona*
Malachite green (leucoform)				
In vivo – In-feed	1·2 g kg^{-1} feed for 10 d (fish species with stomach)	*P. axelrodi* *H. herbertaxelrodi* *H. flammeus* *H. nana* *A. pulcher*	Not effective – all medicated fish died across d 4–10	Ruider *et al*. (1997)
	1·2 g kg^{-1} feed for 10 d (fish species without stomach)	*X. helleri* *B. tetrazona tetrazona* *X. maculates*	Not effective – all medicated fish died across d 4–10	Ruider *et al*. (1997)
Malachite green (p-dimethylaminobenzophenone)				
In vivo – In-feed	1177 mg kg^{-1} feed for 6 d	*H. flammeus* *B. tetrazona tetrazona* *X. helleri*	Not effective – no reduction in trophont numbers on treated fish	Ruider *et al*. (1997)

Malachite green (N,N-dimethylaniline)				
In vivo – In-feed	316 mg kg^{-1} feed for 4 d	*H. nana* *X. heller* *X. maculates*	Not effective – no reduction in trophont numbers on treated fish	Ruider *et al*. (1997)
Methylene blue				
In vitro	100 mg l^{-1} for 2 min	Protomonts	Effective – 100% mortality after 12 h	Post and Vesely (1983)
In vivo – bath (static tanks)	2 mg l^{-1} daily for 20 d	*I. punctatus*	'Effective' – no trophonts on treated fish but 20% fish mortality†	Tieman and Goodwin (2001)
	Alternate days for 20 d: 2 mg l^{-1} and 100 mg l^{-1} formaldehyde (static tanks)		Not effective – no trophonts on treated fish but 40–70% fish mortality†	Tieman and Goodwin (2001)
Metronidazole				
In vitro	25 mg l^{-1} for 3 h	Theronts	Not effective – no details	Wahli *et al*. (1993)
	25 mg l^{-1} for 24 h	Adults**	Not effective – no details	
	25 mg l^{-1} for 24 h	Tomocysts	Not effective – no details	
In vivo – In-feed	7·5 mg kg^{-1} b.w for 7 d	Salmonids not specified	'Effective' – no details	Rahkonen and Koski (2002)
	24 mg kg^{-1} b.w for 10 d	*C. auratus*	Effective – no trophonts on treated fish	Tokşen and Nemli (2010)
	36 mg kg^{-1} b.w for 10 d		Effective – no trophonts on treated fish	
	40 g kg^{-1} feed for 10 d	*O. mykiss*	Not effective – 35% of medicated fish were free of infection	Tojo-Rodriguez and Santamarina-Fernandez (2001)
N-methylglucamine				
In vitro	200 mg l^{-1} for 2 h	Protomonts	Not effective – 12·5% mortality after 2 h; surviving protomonts developed normally	Tojo-Rodriguez *et al*. (1994)
In vivo – bath	200 mg l^{-1} for 6 d	*O. mykiss*	Not effective – all trophonts developed normally	Tojo-Rodriguez *et al*. (1994)
In-feed	1000 mg kg^{-1} feed for 8 d		Not effective – all trophonts developed normally	
	40 g kg^{-1} feed for 10 d	*O. mykiss*	Not effective – all medicated fish had high numbers of trophonts	Tojo-Rodriguez and Santamarina-Fernandez (2001)
MinnFinn™				
See entry for peracetic Acid (PAA) + acetic acid + hydrogen peroxide based formulation (4·5% PAA + 9% AA + 22% H_2O_2)				
Monensin sodium based formulation sold as commercial product as Elancoban				
In vitro	20 mg l^{-1} for 1 h	Trophonts*	Effective – 100% mortality after 14·5 h of exposure	Shinn *et al*. (unpublished)
	50 mg l^{-1} for 1 h		Effective – 100% mortality after 14·5 h of exposure	
	100 mg l^{-1} for 1 h	Trophonts*	Effective – 100% mortality	Shinn *et al*. (2001)
	20 mg l^{-1} for 1 h	Theronts	Not effective – 27·4% mortality	Shinn *et al*. (unpublished)
	50 mg l^{-1} for 1 h		Not effective – 36·8% mortality	
	100 mg l^{-1} for 1 h		Partially effective – 48·2% mortality	Shinn *et al*. (2001)
In vivo – In-feed	2 mg kg^{-1} feed for 10 d		Not effective – no significant reduction in trophont numbers	Shinn *et al*. (unpublished)
	5 mg kg^{-1} feed for 10 d		Not effective – no significant reduction in trophont numbers	

Table 1. (*Cont.*)

Compound	Dose	Host/parasite stage	Efficacy	Reference
	10 mg kg^{-1} feed for 10 d		Not effective – no significant reduction in trophont numbers	
	100 mg kg^{-1} feed for 10 d prior to inf.	*O. mykiss*	Not effective – no reduction in trophont numbers	Shinn *et al*. (2003*a*)
Mucuna pruriens (velvet bean)				
In vitro	100 mg l^{-1} for 3 h	Trophonts*	Not effective – 0% mortality	Ekamen *et al*. (2004)
	100 mg l^{-1} for 6 h		Partially effective – 65% mortality	
	150 mg l^{-1} for 3 h		Not effective – 25% mortality	
	150 mg l^{-1} for 6 h		Effective – 100% mortality	
	200 mg l^{-1} for 3 h		Not effective – 35% mortality	
	200 mg l^{-1} for 6 h		Effective – 100% mortality	
In vivo – bath	100 mg l^{-1} for 72 h	*C. a. auratus*	Partially effective – 59% reduction on the skin/60% on the gills	Ekamen *et al*. (2004)
	150 mg l^{-1} for 72 h		Effective – 79% reduction in trophonts on the skin/ 83% on the gills	
	200 mg l^{-1} for 72 h		Effective – 92% reduction in trophonts on the skin/ 91% on the gills	
Na-desoxycholate				
In vitro	25 mg l^{-1} for 3 h	Theronts	Not effective – no details	Wahli *et al*. (1993)
	25 mg l^{-1} for 24 h	Adults**	Not effective – no details	
	25 mg l^{-1} for 24 h	Tomoysts	Not effective – no details	
Netobimin				
In vivo – In-feed	40 g kg^{-1} feed for 10 d	*O. mykiss*	Partially effective – 75% of medicated fish with moderate number of trophonts	Tojo-Rodriguez and Santamarina-Fernandez (2001)
Nicarbazin				
In vivo – In-feed	100 mg kg^{-1} feed for 10 d prior inf.	*O. mykiss*	Not effective – no reduction in trophont numbers on treated fish	Shinn *et al*. (2003*a*)
Niridazole				
In vivo – In-feed	40 g kg^{-1} feed for 10 d	*O. mykiss*	Effective – 90% of medicated fish with low numbers of trophonts	Tojo-Rodriguez and Santamarina-Fernandez (2001)
Nitroscanate				
In vivo – In-feed	40 g kg^{-1} feed for 10 d	*O. mykiss*	Partially effective – 50% of medicated fish had no trophonts	Tojo-Rodriguez and Santamarina-Fernandez (2001)
N-methylglucamine				
In vivo – In-feed	40 g kg^{-1} feed for 10 d	*O. mykiss*	Not effective – all medicated fish had high numbers of trophonts	Tojo-Rodriguez and Santamarina-Fernandez (2001)

Ornidazole				
In vivo – In-feed	24 mg kg^{-1} b.w for 10 d	*C. auratus*	Effective – no trophonts on the treated groups	Tokşen and Nemli (2010)
	36 mg kg^{-1} b.w for 10 d		Effective – no trophonts on the treated groups	
Oxytetracycline				
In vitro	100 mg l^{-1} for 3 h	Theronts	Not effective – medium survival rate after 3 h	Wahli *et al*. (1993)
	100 mg l^{-1} for 24 h	Adults**	Not effective – high survival rate after 24 h	
	100 mg l^{-1} for 24 h	Tomocysts	Not effective – high survival rate after 24 h	
Paromomycin				
In vitro	200 mg l^{-1} for 2 h		Partially effective – 75% mortality after 2 h, surviving protomonts reproduce normally	Tojo-Rodriguez *et al*. (1994)
In vivo – bath	200 mg l^{-1} for 3 h	*O. mykiss*	Not effective – all trophonts developed normally	Tojo-Rodriguez *et al*. (1994)
In-feed	1000 mg kg^{-1} for 8 d		Not effective – all trophonts developed normally	
Peracetic acid (PAA) + acetic acid + hydrogen peroxide based formulation (40%PAA + 25%AA + 15%H_2O_2) sold as commercial product as Wofasteril®				
In vitro	0·4 mg l^{-1} for 48 h	Protomonts	Not effective – 21% mortality	Meinelt *et al*. (2009)
	0·5 mg l^{-1} for 48 h		Not effective – 20% mortality	
	0·6 mg l^{-1} for 48 h		Not effective – 39% mortality	
	0·7 mg l^{-1} for 48 h		Not effective – $\sim$ 40% mortality	
	0·8 mg l^{-1} for 48 h		Partially effective – $\sim$ 75% mortality	
	0·9 mg l^{-1} for 48 h		Effective – 82% mortality	
	0·5 mg l^{-1} for 12 h	Tomocysts (< 2·5 h)	Not effective – 42% mortality	Meinelt *et al*. (2009)
	1 mg l^{-1} for 12 h		Partially effective – 75% mortality	
	2 mg l^{-1} for 12 h		Effective – 98% mortality	
	3 mg l^{-1} for 12 h		Effective – > 99% mortality	
	0·5 mg l^{-1} for 2 h	Tomocysts (24 h +)	Not effective – all trophonts developed normally	Meinelt *et al*. (2009)
	0·5 mg l^{-1} for 4 h		Not effective – all trophonts developed normally	
	1 mg l^{-1} for 2 h		Not effective – all trophonts developed normally	
	1 mg l^{-1} for 4 h		Not effective – all trophonts developed normally	
	2 mg l^{-1} for 2 h		Not effective – all trophonts developed normally	
	2 mg l^{-1} for 4 h		Not effective – all trophonts developed normally	
	2·5 mg l^{-1} for 2 h		Not effective – all trophonts developed normally	
	3 mg l^{-1} for 2 h		Not effective – all trophonts developed normally	
	2·5 mg l^{-1} for 4 h		Not effective – all trophonts developed normally	
	0·04 mg l^{-1} for 1–4 h	Theronts	Not effective – 0–5% mortality	Straus and Meinelt (2009)
	0·08 mg l^{-1} for 1–4 h		Not effective – 0–5% (trial 1); 10–20% mortality (trial 2)	
	0·12 mg l^{-1} for 1–4 h		Not effective – 5–10% (trial 1); 20–30% mortality (trial 2)	
	0·16 mg l^{-1} for 1–3 h		Not effective – 20–40% mortality	
	0·16 mg l^{-1} for 4 h		Partially effective – 50% mortality	
	0·20 mg l^{-1} for 1 h		Not effective – 40% mortality	
	0·20 mg l^{-1} for 1–4 h		Not effective – 30% mortality	
	0·20 mg l^{-1} for 2–4 h		Partially effective – 50% mortality	

Table 1. (*Cont.*)

Compound	Dose	Host/parasite stage	Efficacy	Reference
	0·24 mg l^{-1} for 1–4 h		Not effective – 30% mortality (trial 1); 60% mortality (trial 2)	
	0·28 mg l^{-1} for 1–4 h		Partially effective – 50% mortality (trial 1); 70–80% mortality (trial 2)	
	0·32 mg l^{-1} for 1–4 h		Effective – 60% mortality (trial 1); 80–90% mortality (trial 2)	
	0·36 mg l^{-1} for 1–4 h		Effective – 70% mortality (trial 1); 80–95% mortality (trial 2)	
	0·40 mg l^{-1} for 1–4 h		Effective – 80% mortality (trial 1); 90–95% mortality (trial 2)	
In vivo – bath (40% PAA solution)				
	1 mg l^{-1} for 4 d	*C. carpio*	Effective – significant reduction on the number of trophonts on treated fish	Sudová *et al*. (2010)
Peracetic Acid (PAA) + hydrogen peroxide + based formulation (4·5% PAA + 22% H_2O_2 + 9% AA) sold as the commercial product as MinnFinn™				
In vitro				
(theronts from *Notemigonus crysoleucas*)				
	0·0225 mg l^{-1} for 1–4 h		Not effective – 0% mortality	Straus and Meinelt (2009)
	0·0450 mg l^{-1} for 1–4 h		Not effective – 0% mortality	
	0·0675 mg l^{-1} for 1–4 h		Not effective – 5% mortality	
	0·0900 mg l^{-1} for 1–4 h		Not effective – 5–20% mortality	
	0·1125 mg l^{-1} for 1–4 h		Not effective – 20–40% mortality	
	0·1350 mg l^{-1} for 1 h		Not effective – 30% mortality	
	0·1350 mg l^{-1} for 2–4 h		Partially effective – 50% mortality	
	0·1575 mg l^{-1} for 1 h		Not effective – 40% mortality	
	0·1575 mg l^{-1} for 2–4 h		Partially effective – 60% mortality	
	0·1800 mg l^{-1} for 1 h		Not effective – 40% mortality	
	0·1800 mg l^{-1} for 2–4 h		Partially effective – 60% mortality	
	0·2025 mg l^{-1} for 1 h		Not effective – 40% mortality	
	0·2025 mg l^{-1} for 2–4 h		Partially effective – 70% mortality	
	0·2250 mg l^{-1} for 1–4 h		Partially effective – 50–70% mortality	
(theronts from *Xiphophorus hellerii*)				
	0·0225 mg l^{-1} for 1–4 h		Not effective – 0–10% mortality	
	0·0450 mg l^{-1} for 1–4 h		Not effective – 10% mortality	
	0·0675 mg l^{-1} for 1–4 h		Not effective – 10–20% mortality	
	0·0900 mg l^{-1} for 1–4 h		Not effective – 10–30% mortality	
	0·1125 mg l^{-1} for 1–3 h		Not effective – 20–40% mortality	
	0·1125 mg l^{-1} for 4 h		Partially effective – 50% mortality	
	0·1350 mg l^{-1} for 1 h		Not effective – 40% mortality	
	0·1350 mg l^{-1} for 2–4 h		Partially effective – 50% mortality	
	0·1575 mg l^{-1} for 1–4 h		Partially effective – 50–60% mortality	
	0·1800 mg l^{-1} for 1–4 h		Effective – 60–80% mortality	

	0·2025 mg l^{-1} for 1–4 h		Effective – 60–90% mortality	
	0·2250 mg l^{-1} for 1–4 h		Effective – 70–95% mortality	
Peracetic acid + acetic acid + hydrogen peroxide based formulation sold as the commercial product Detarox				
In vivo – bath	10 mg l^{-1} for 25–45 min 2nd treatment after 4–7 d	Salmonids – not specified	'Effective' – no details	Rhakonen and Koski (2002)
Peracetic acid + acetic acid + hydrogen peroxide based formulation (13% PAA + 20% AA + 20% H_2O_2) sold as commercial product Per Aqua				
In vitro	0·08 mg l^{-1} for 30 min up to 60 min	Protomonts	Not effective – 0–20% mortality	Bruzio and Buchmann (2010)
	0·08 mg l^{-1} for 1·5 h up to 4·5 h		Not effective – 30–40% mortality	
	0·8 mg l^{-1} for 15 min		Not effective – 20% mortality	
	0·8 mg l^{-1} for 30 min		Effective – ~ 90% mortality	
	0·8 mg l^{-1} for 45 min		Effective – ~ 100% mortality	
	0·8 mg l^{-1} for 15 min	Theronts	Effective – 100% mortality	
	8 mg l^{-1} for 15 min		Effective – 100% mortality	
In vivo – bath	40 mg l^{-1} 3 times a week for 3 weeks	*S. salar*	Not effective – infections rose throughout the infection period	Rintamäki-Kinnunen *et al.* (2005*a*)
Peracetic acid + acetic acid + hydrogen peroxide based formulation (13% PAA + 20% AA + 20% H_2O_2) sold as commercial product Desirox + formaldehyde				
In vivo – bath	10 + 100 mg l^{-1} 3 times a week for 4 weeks	*S. salar*	Trial inconclusive – details missing	Rintamäki-Kinnunen *et al.* (2005*a*)
Peracetic acid + acetic acid + hydrogen peroxide + peroctanoic acid based formulation sold as commercial product Incimaxx Aquatic				
In vitro	0·08 mg l^{-1} for 30 min up to 4·5 h	Protomonts	Not effective – ~ 15–20% mortality	
	0·8 mg l^{-1} for 15 min		Not effective – 40% mortality	Bruzio and Buchmann (2010)
	0·8 mg l^{-1} for 30 min		Effective – 80% mortality	
	0·8 mg l^{-1} for 45 min		Effective – 100% mortality	
	8 mg l^{-1} for 1 h		Effective – 100% mortality	Picón-Camacho *et al.* (in press *b*)
	12 mg l^{-1} for 1 h		Effective – 100% mortality	
	15 mg l^{-1} for 1 h		Effective – 100% mortality	
	8 mg l^{-1} for 1 h	Tomocysts	Effective – 100% mortality	Picón-Camacho *et al.* (in press *b*)
	12 mg l^{-1} for 1 h		Effective – 100% mortality	
	15 mg l^{-1} for 1 h		Effective – 100% mortality	
	0·8 mg l^{-1} for 15 min	Theronts	Effective – 100% mortality	Bruzio and Buchmann (2010)
	8 mg l^{-1} for 15 min		Effective – 100% mortality	
	8 mg l^{-1} for 1 h		Effective – 98·3% mortality	Picón-Camacho *et al.* (in press *b*)
	12 mg l^{-1} for 1 h		Effective – 100% mortality	
	15 mg l^{-1} for 1 h		Effective – 100% mortality	

Per Aqua

See entry for peracetic acid + acetic acid + hydrogen peroxide based formulations (13% PAA + 20%AA + 20%H_2O_2)

Perotan

See entry for hydrogen peroxide + acetic acid based formulations

Table 1. (*Cont.*)

Compound	Dose	Host/parasite stage	Efficacy	Reference
Piscidin 2 (antimicrobial polypeptide)				
In vitro	12·5 μg ml^{-1} for 9 min 46 s	Trophonts*	Effective – 100% mortality	Ullal *et al*. (2008)
	25 μg ml^{-1} for 7 min 33 s		Effective – 100% mortality	
	50 μg ml^{-1} for 6 min		Effective – 100% mortality	
	100 μg ml^{-1} for 6 min 15 s		Effective – 100% mortality	
	200 μg ml^{-1} for 6 min 25 s		Effective – 100% mortality	
	3·1 μg ml^{-1} for 4 h	Theronts	Not effective – 0% killed, but less active than those in the controls	Colorni *et al*. (2008)
	6·3 μg ml^{-1} for 10 min		Effective – 100% mortality	
	12·5 μg ml^{-1} for 10 min		Effective – 100% mortality	
	100 μg ml^{-1} for 5 min		Effective – 100% mortality	
Piperazine				
In vivo – In-feed	40 g kg^{-1} feed for 10 d	*O. mykiss*	Partially effective – 55% of the medicated fish had a low number of trophonts	Tojo-Rodriguez and Santamarina-Fernandez (2001)
Potassium ferrate (VI)				
In vitro	0·096 for 30 min up to 4 h	Theronts	Not effective – 0% mortality	Ling *et al*. (2010)
	0·96 mg l^{-1} for 30 min and 1 h		Not effective – 0% mortality	
	0·96 mg l^{-1} for 2 h		Not effective – 14% mortality	
	0·96 mg l^{-1} for 4 h		Not effective – 25% mortality	
	1·92 mg l^{-1} for 30 min		Not effective – 0% mortality	
	1·92 mg l^{-1} for 1 h		Not effective – 20% mortality	
	1·92 mg l^{-1} for 2 h		Not effective – 24% mortality	
	1·92 mg l^{-1} for 4 h		Partially effective – 56% mortality	
	4·80 mg l^{-1} for 30 min		Not effective – 38% mortality	
	4·80 mg l^{-1} for 1 h		Partially effective – 58% mortality	
	4·80 mg l^{-1} for 2 h		Effective – 100% mortality	
	9·60 mg l^{-1} for 30 min		Partially effective – 50% mortality	
	9·60 mg l^{-1} for 1 h		Partially effective – 64% mortality	
	9·60 mg l^{-1} for 2 h		Effective – 100% mortality	
	14·40 mg l^{-1} for 30 min		Partially effective – 59% mortality	
	14·40 mg l^{-1} for 1 h		Effective – 100% mortality	
	19·20 mg l^{-1} for 30 min		Partially effective – 69% mortality	
	19·20 mg l^{-1} for 1 h		Effective – 100% mortality	
	24·00 mg l^{-1} for 30 min		Effective – 100% mortality	
	48·00 mg l^{-1} for 30 min		Effective – 100% mortality	
In vivo – bath	1·92 mg l^{-1} for 3 d	*C. auratus*	Partially effective – 71·94% trophont reduction	Ling *et al*. (2010)
	4·80 mg l^{-1} for 3 d		Effective – 80·30% trophont reduction	
	9·60 mg l^{-1} for 3 d		Effective – 83·39% trophont reduction	
	19·20 mg l^{-1} for 3 d		Effective – 100% trophont reduction	

Potassium permanganate ($KMnO_4$)				
In vitro	0·1 – 0·5 mg l^{-1} for 15 up to 45 min	Theronts	Not effective – no details	Straus and Griffin (2001)
	0·6 mg l^{-1} for 15 min up to 4 h		Not effective – 0–1% mortality	
	0·7 mg l^{-1} for 15 min up to 4 h		Not effective – 5–10% mortality	
	0·8 mg l^{-1} for 15 min		Not effective – 0% mortality	
	0·8 mg l^{-1} for 30 min up to 4 h		Partially effective – 70% mortality	
	0·9 mg l^{-1} for 15 min		Not effective – 0% mortality	
	0·9 mg l^{-1} for 30 min up to 4 h		Effective – 90–95% mortality	
	1·0 mg l^{-1} for 15 min		Not effective – 0% mortality	
	1·0 mg l^{-1} for 30 min up to 4 h		Effective – 95 – > 99% mortality	
In vivo – bath	0·25 mg l^{-1} for 6 d	*I. punctatus*	Partially effective – low number of trophonts on treated fish	Straus and Griffin (2001)
	0·50 mg l^{-1} for 6 d		Partially effective – low number of trophonts on treated fish	
	0·75 mg l^{-1} for 6 d		Partially effective – low number of trophonts on treated fish	
	1·0 mg l^{-1} for 6 d		Effective – No trophonts on treated fish	
	2 mg l^{-1} daily for 20 d (static tanks and flow through)	*I. punctatus*	Not effective – all treated infected fish died; trophonts present	Tieman and Goodwin (2001)
	0·25 mg l^{-1} for 8 d	*Tilapia aurea*	Effective – No trophonts on treated fish	Straus and Griffin (2001)
	0·50 mg l^{-1} for 8 d		Effective – No trophonts on treated fish	
	0·5 mg l^{-1} daily for 10 d	*I. punctatus*	Not effective – high number of trophonts on treated fish	Straus and Griffin (2002)
	0·75 mg l^{-1} daily for 10 d		Not effective – high number of trophonts on treated fish	
	1·0 mg l^{-1} daily for 10 d		Effective – no trophonts on treated fish	
	1·25 mg l^{-1} daily for 10 d		Effective – no trophonts on treated fish	
	1·25 mg l^{-1} daily for 10 d		Not effective – toxic to treated fish	
	4 mg l^{-1} 3 times a week for 2 weeks	*S. salar*	Trial inconclusive – low parasite numbers across all groups	Rintamäki-Kinnunen *et al*. (2005*a*)
	10–20 mg l^{-1} for 30 min	*O. mykiss* *S. fontinalis* *S. trutta*	'Effective' – there was a reduction in trophont number on treated fish but was toxic to all three fish species	Balta *et al*. (2008)
Potassium permanganate ($KMnO_4$) + dimetrazole				
In vivo – bath + in-feed	3 mg l^{-1} every 2nd d, 5 times + dimetrazole in feed 28 mg/fish for 10 d	*O. mykiss*	Effective – no signs of infection by d 7	Rapp (1995)
Potassium persulfate + sodium dodecylbenzosulfonate + malic acid + sulfamic acid based formulation commercialised as Virkon S				
In vitro	1 mg l^{-1} for 1 h	Theronts	Not effective – ~ 8% mortality	Shinn *et al*. (2005)
	10 mg l^{-1} for 1 h		Partially effective – ~ 55% mortality	
	100 mg l^{-1} for 1 h		Not effective – 60% mortality†	
	< 50 μl l^{-1} for 10 h	Trophonts*	Not effective – trophonts develop normally	Lahnsteiner and Weismann (2007)

Table 1. (*Cont.*)

Compound	Dose	Host/parasite stage	Efficacy	Reference
In vivo – bath	10 μl l^{-1} for 2 h for 5 d	*O. mykiss*	Not effective – none of the treated fish survived	Lahnsteiner and Weismann (2007)
	10 μl l^{-1} for 4 h for 5 d	*C. carpio*	Not effective – 90% of the treated fish had survived on d 1; 50% were still alive by d3 but had a high number of trophonts	
Pyceze™				
See entry for bronopol				
Quinacrine				
In vitro	200 mg l^{-1} for 2 h	Protomonts	Partially effective – 50% mortality after 2 h; 50% of protomonts develop normally	Tojo-Rodriguez *et al.* (1994)
In vivo – bath	100 mg l^{-1} for 3 h, d 6 p.i.	*O. mykiss*	Not effective – 50% fish mortality; all trophonts developed normally	
In-feed	500 mg kg^{-1} for 8 d		Not effective – all trophonts developed normally; signs of feed rejection from d 4	
Quinine				
In vivo – In-feed	5 g kg^{-1} feed for 7 d	*Poecilia sphenops*	Effective – 100% elimination of trophonts	Schmahl *et al.* (1996)
	5 g kg^{-1} feed for 8 d	*X. heller*	Effective – 100% elimination of trophonts	
	5 g kg^{-1} feed for 10 d	*Hyphessobrycon herbertaxelrodi*	Effective – 100% elimination of trophonts	
1,3-di-6-quinolylurea				
In vivo – In-feed	40 g kg^{-1} feed for 10 d	*O. mykiss*	Not effective – all treated fish had a high number of trophonts	Tojo-Rodriguez and Santamarina-Fernandez (2001)
Ronidizole (1-methyl-2-carboxymethyl-5-nitroimidazole)				
In vitro	250 mg l^{-1} for 1 h – 48 h	Trophozites*	Not effective – 0% mortality	Farley and Heckmann (1980)
	500 mg l^{-1} for 1 h – 4 h		Not effective – 0% mortality	
	500 mg l^{-1} for 8 h		Not effective – 25% mortality	
	500 mg l^{-1} for 24 h		Partially effective – 65·5% mortality (3 repeat trials)	
	500 mg l^{-1} for 48 h		Partially effective – 65·5% mortality	
	750 mg l^{-1} for 1 h		Not effective – 0% mortality	
	750 mg l^{-1} for 2 h		Not effective – 2·5% mortality	
	750 mg l^{-1} for 4 h		Not effective – 47·5% mortality	
	750 mg l^{-1} for 8 h		Effective – 82·5% mortality	
	750 mg l^{-1} for 24 h		Effective – 87·5% mortality (trial 1); 100% mortality (trial 2)	
	500 mg l^{-1} for 1 h	Tomites	Not effective – 10% mortality	Farley and Heckmann (1980)
	500 mg l^{-1} for 2 h		Not effective – 23% mortality	
	500 mg l^{-1} for 4, 8 and 24 h		Effective – 55%, 90% and 96% mortality respectively	

	750 mg l^{-1} for 1 h		Not effective – 19% mortality	
	750 mg l^{-1} for 2, 4, 8 and 24 h		Effective – 51·5%, 77·5%, 79% and 96·5% mortality respectively	
In vivo – In-feed	40 g kg^{-1} feed for 10 d	*O. mykiss*	Not effective – 100% medicated fish high number of trophonts	Tojo-Rodriguez and Santamarina-Fernandez (2001)
SalarBec				
In vivo – In-feed	0·32 mg kg^{-1} feed for 10 d prior infection	*O. mykiss*	Partially effective – 65% trophont reduction	Shinn *et al*. (2005)
Salinomycin sodium				
In vivo – In-feed	38 mg kg^{-1} feed for 10 d p.i.	*O. mykiss*	Effective – 80·2% trophonts reduction	Shinn *et al*. (2003*b*)
	43 mg kg^{-1} feed for 10 d p.i.		Partially effective – 71·9% trophonts reduction	
	47 mg kg^{-1} feed for 10 d p.i.		Effective – 93·3% trophonts reduction	
Secnidazole				
In vivo – In-feed	24 mg kg^{-1} b.w for 10 d	*C. auratus*	Effective – no trophonts on treated fish	Tokşen and Nemli (2010)
	36 mg kg^{-1} b.w for 10 d		Effective – no trophonts on treated fish	
	40 g kg^{-1} feed for 10 d	*O. mykiss*	Partially effective – 75% medicated fish free of infection	Tojo-Rodriguez and Santamarina-Fernandez (2001)
Silver nitrate				
In vitro	0·67 mg l^{-1}	Tomites	Effective – 100% mortality in less than 15 sec	Farley and Heckmann (1980)
Sodium carbonate peroxyhydrate				
In vivo – bath	60–90 mg l^{-1} daily for 30–1 h for 4–6 d	Not specified	Not effective – no details	Rahkonen and Koski (2002)
Sodium chloride (NaCl)				
In vitro	2·5 g l^{-1} for 24 h	Theronts	Partially effective – ~ 50% mortality	Shinn *et al*. (2005)
	5 g l^{-1} for 24 h		Effective – ~ 95% mortality	
	10 g l^{-1} for 24 h		Effective – ~ 98% mortality	
	15 g l^{-1} for 10 h	Trophonts*	Not effective – 0% mortality	Lahnsteiner and Weismann (2007)
	20 g l^{-1} for 10 h		Effective – 100% mortality	
In vivo – bath	1 g l^{-1} for 12 d	*B. bidyanus*	100% theronts killed; trophonts 57% lower than controls* (8·7 ± 15·1% fish survive *vs* 0% of control fish)	Mifsud and Rowland (2008)
	1 g l^{-1} for 16 d		Theronts 74·9% and trophonts 89·8% lower than controls* (96·7 ± 4·7% fish survive *vs* 66·7 ± 47·1% of control fish)	
	2 g l^{-1} for 12 d		100% theronts and protomonts mortality* (96·7 ± 4·7% fish survive *vs* 0% of control fish)	
	2 g l^{-1} for 16 d		100% theronts and protomonts mortality* (96·7 ± 4·7% fish survive *vs* 66·7 ± 47·1% of control fish)	

Table 1. (*Cont.*)

Compound	Dose	Host/parasite stage	Efficacy	Reference
	3 g l^{-1} for 16 d		100% theronts and protomonts mortality* (100% fish survive *vs* 66·7 ± 47·1% of control fish)	
	3 g l^{-1} daily for 20 d (static tanks)	*I. punctatus*	Not effective – all treated fish died	Tieman and Goodwin (2001)
	4 g l^{-1} for 45 d	*Rhamdia quelen*	24·7% of the treated fish survived *versus* 8·1% of the control fish	Miron *et al*. (2003)
	4 g l^{-1} daily for 30 d	*R. quelen*	'Effective' – reduction in the number of trophonts on treated fish	Garcia *et al*. (2007)
	5 g l^{-1} for 14 d at 11–18 °C	*B. bidyanus*	Effective – no trophonts visible on treated fish	Selosse and Rowland (1990)
	5 g l^{-1} for 8 d at 24 °C	*B. bidyanus*	Effective – no trophonts visible on treated fish	
	5 g l^{-1} for 7 d at 19–22 °C	*Maccullochella peeli*	Effective – no trophonts visible on treated fish	
	5 g l^{-1} for 7 d at 23–26 °C	*Tandanus tandanus*	Effective – no trophonts visible on treated fish	
	10 and 15 g l^{-1} for 20 min	*O. mykiss* *S. fontinalis* *S. trutta*	Not effective – no details	Balta *et al*. (2008)
	20 g l^{-1} for 1 h for 5 d	*O. mykiss*	Partially effective – 60% of treated fish survived, no infections on d1 but a high infection on d 3	Lahnsteiner and Weismann (2007)
	20 g l^{-1} for 1 h for 5 d	*C. carpio*	Not effective – 0% survival on treated fish†; no infections d 1 but high infection on d 3	
	20 g l^{-1} for 20 min	*O. mykiss* *S. fontinalis* *S. trutta*	'Effective' – reduction in the number of trophotns on treated fish	Balta *et al*. (2008)
In-feed	0·3–1·0% feed for 3–11 d	*C. carpio*	'Effective' – no details	Rahkonen and Koski (2002)
	1·2% feed for 30 d	*R. quelen*	Not effective – high mortality within the treated groups	Garcia *et al*. (2007)
	2·5% feed for 30 d		Not effective – high mortality within the treated groups	
	5·0% feed for 30 d		Not effective – high mortality on treated groups	
	6·0% feed for 30 d		Not effective – high mortality on treated groups	
Sodium percarbonate				
In vitro	12·5 mg l^{-1} for 3 h	Theronts/tcysts	Effective on theronts but not effective on tomocysts	Jensen *et al*. (2001)
	12·5 mg l^{-1} for 24 h	Tomocysts	Not effective – 11% mortality	
	13 mg l^{-1} for few hours (no details)		Effective on theronts but not effective on tomocysts	
	63 mg l^{-1} for 1 h		Effective on theronts but not effective on tomocysts	Buchmann *et al*. (2003)
	512 mg l^{-1} for <1 h	Protomonts	Effective – 100% mortality	Heinecke and Buchmann (2009)
	256 mg l^{-1} for <1 h 30 min		Effective – 100% mortality	

	128 mg l^{-1} for <4 h 15 min		Effective – 100% mortality	
	0·5 mg l^{-1} for 1·5, 3 and 15 h	Theronts	Not effective – < 50% mortality	Buchman *et al*. (2003)
	2·5 mg l^{-1} for 1·5, 3 and 15 h		Not effective – < 50% mortality	
	8 mg l^{-1} for 30–60 min		Not effective – ~ 0% mortality	Bruzio and Buchmann (2010)
	8 mg l^{-1} for 1·5 h		Not effective – ~ 40% mortality	
	8 mg l^{-1} for 2 h		Partially effective – ~ 70% mortality	
	8 mg l^{-1} for 2·5 h		Partially effective – ~ 70% mortality	
	8 mg l^{-1} for 3 h		Effective – ~ 100% mortality	
	8 mg l^{-1} for ~5 h (11–12 °C)		Effective – 100% mortality	Heinecke and Buchmann (2009)
	8 mg l^{-1} for ~2 h 20 min (21–22 °C)		Effective – 100% mortality	
	12·5 mg l^{-1} for 1·5 h		Not effective – < 50% mortality	Buchman *et al*. (2003)
	12·5 mg l^{-1} for 3 and 15 h		Partially effective – > 50% mortality	
	16 mg l^{-1} for ~1 h 20 min (11–12 °C)		Effective – 100% mortality	Heinecke and Buchmann (2009)
	16 mg l^{-1} for ~1 h 40 min (21–22 °C)		Effective – 100% mortality	
	32 mg l^{-1} for ~1 h 10 min (11–12 °C)		Effective – 100% mortality	
	32 mg l^{-1} for ~30 min (21–22 °C)		Effective – 100% mortality	
	62·5 mg l^{-1} for 1·5, 3 and 15 h		Partially effective – > 50% mortality	Buchman *et al*. (2003)
	64 mg l^{-1} for ~30 min (11–12 °C)		Effective – 100% mortality	Heinecke and Buchmann (2009)
	64 mg l^{-1} for ~10 min (21–22 °C)		Effective – 100% mortality	
	312·5 mg l^{-1} for 1·5, 3 and 15 h		Partially effective – > 50% mortality	Buchman *et al*. (2003)
	1562·5 mg l^{-1} for 1·5, 3 and 15 h		Partially effective – > 50% mortality	
In vivo – bath	Concentration not specified for 20 min every 2nd and 3rd day	*O. mykiss*	Not effective – no details	Rahkonen and Koski (2002)
Sulfachlorpyrazine				
In vitro	100 mg l^{-1} for 3 h	Theronts	Not effective – high survival rate after 3 h	Wahli *et al*. (1993)
	100 mg l^{-1} for 24 h	Adults**	Not effective – high survival rate after 24 h	
	100 mg l^{-1} for 24 h	Tomocysts	Not effective – high survival rate after 24 h	
Sulfaquinoxaline				
In vitro	200 mg l^{-1} for 2 h	Protomonts	Not effective – 12·5% mortality after 2 h; protomonts surviving treatment developed normally	Tojo-Rodriguez *et al*. (1994)
In vivo – bath	200 mg l^{-1} for 3 h, day 6 p.i.	*O. mykiss*	Not effective – all protomonts developed normally	Tojo-Rodriguez *et al*. (1994)
In-feed	1000 mg kg^{-1} for 8 d		Not effective – all protomonts developed normally; 4% fish mortality on day 6 p.i.; no feed unpalatability	
Thiophanate				
In vivo – In-feed	40 g kg^{-1} feed for 10 d	*O. mykiss*	Not effective – 100% medicated fish high number of trophonts	Tojo-Rodriguez and Santamarina-Fernandez (2001)
Toltrazuril				

Table 1. (*Cont.*)

Compound	Dose	Host/parasite stage	Efficacy	Reference
In vitro	10 μg ml^{-1} for 2 h	Protomonts	Effective – 100% mortality	Schmahl *et al*. (1989)
	200 mg l^{-1} for 2 h		Effective – 0% mortality but protomonts did not develop	Tojo-Rodriguez *et al*. (1994)
	< 50 mg l^{-1} for 10 h	Trophonts*	Not effective – trophonts developed normally	Lahnsteiner and Weismann (2007)
	10 μg ml^{-1} for 2 h	Theronts	Not effective – 0% mortality	Schmahl *et al*. (1989)
In vivo – bath	d1 10 mg l^{-1} (2 h) d2 and d3 20 mg l^{-1} (1 h)	Various spp.	Trophonts affected but not theronts	Mehlhorn *et al*. (1988)
	d1 10 mg/l (4 h) d3 and d5 10 mg/l (4 h)	Various spp.	100% trophonts killed but theronts not affected	Mehlhorn *et al*. (1988)
	1 μg ml^{-1} for 4·5 h	*A. rostrata*	Not effective – no details	Schmahl *et al*. (1989)
	5 μg ml^{-1} for 4·5 h	*A. rostrata*	Not effective – one third of the parasites dropped off the fish within 24 h. New infections established within 2 d	
	10 μg ml^{-1} for 2 h		Effective – two thirds of the parasites dropped off the fish within 24 h, fish were free from new infections over the following 14 days	
	10 μg ml^{-1}, 2 h (1st d) 20 μg ml^{-1}, 1 h (2nd d) 20 μg ml^{-1}, 2 h (3rd d)	*A. rostrata*	'Effective' – no details	Schmahl *et al*. (1989)
	5 mg l^{-1}	*O. mykiss*	Not effective – toxic, after 5 h 100% fish mortality	From *et al*. (1992)
	10 mg l^{-1}		Not effective – toxic, after 3·5 h 100% fish mortality	
	20 mg l^{-1}		Not effective – toxic, after 2 h 100% fish mortality	
	50 mg l^{-1}		Not effective – toxic, after 2 h 100% fish mortality	
	200 mg l^{-1} for 3 h, day 6 p.i.	*O. mykiss*	Not effective – all trophonts developed normally	Tojo-Rodriguez *et al*. (1994)
In-feed	1000 mg kg^{-1} for 8 d	*O. mykiss*	Not effective – all trophonts developed normally	Tojo-Rodriguez *et al*. (1994)
Tramisol (6S)-6-phenyl-2,3,5,6-tetrahydroimidazo[2,1-b][1,3]thiazole)				
In vitro	100 mg l^{-1} for 2 min	Trophozoites*	Effective – 50% mortality after 2 h; 100% mortality post exposure	Post and Vesley (1983)
Tricaine methanesulfonate (TM)				
In vitro	50 mg l^{-1} buffered with Na $CaCO_3$ (time of exposure not specified)	Protomonts	Not effective – 4·9% mortality	Xu *et al*. (2008)
	50 mg l^{-1} not buffered (time of exposure not specified)		Not effective – 1·1% mortality	
	150 mg l^{-1} buffered with Na $CaCO_3$ for 2–3 min		Not effective – 1·8% mortality	
	150 mg l^{-1} buffered with Na $CaCO_3$ (time of exposure not specified)		Not effective – 9·2% mortality	
	150 mg l^{-1} not buffered for 2–3 min		Not effective – 6·1% mortality	

	150 mg l^{-1} not buffered (time of exposure not specified)		Not effective – 9·9% mortality	
	300 mg l^{-1} buffered with Na $CaCO_3$ (time of exposure not specified)		Not effective – 7·3% mortality	
	300 mg l^{-1} not buffered (time of exposure not specified)		Effective – 100% mortality	
Triclabendazole (5-choloro-6-(2, 3-dichlorophenoxy)-2-methylthio-1H- benzimidazole)				
In vivo – In-feed	20 g kg^{-1} feed for 10 d	*O. mykiss*	Not effective – 100% medicated fish with >50 trophonts	Luzardo-Álavarez *et al*. (2003)
Triclabendazole + β-cyclodextrin (ratio 1:2)				
In vivo – In-feed	10 g kg^{-1} feed for 10 d	*O. mykiss*	Partially effective – 58% reduction in trophont number compared to control	Luzardo-Álavarez *et al*. (2003)
	20 g kg^{-1} feed for 10 d		Partially effective – 42% reduction in trophont number compared to control	
Vitamin C				
See entry for ascorbate-2-phosphate				
Vitamin E				
See entry for d-1-alpha-tocopheryl acetate				
Violet C				
In vivo – bath	0·01 mg l^{-1} for 2 d	*C. carpio*	Not effective – not specified	Kurovskaya (2005)
	0·02 mg l^{-1} for 6 d		Effective – no trophonts on treated fish	
	50 mg l^{-1} for 30 min		Effective – no trophonts on treated fish	
Virkon S				
See the entry for potassium persulfate + sodium dodecylbenzosulfonate + malic acid + sulfamic acid based formulation				
Wofasteril®				
See entry peracetic Acid (PAA) + hydrogen peroxide + acetic acid (40% PAA + 15% H_2O_2 + 25% AA)				

Abbreviations: d: days; h: hours; inf.: infection; p.i.: post-infection; *****authors use the term 'throphont/trophozites' for the free-swimming stage which exited the fish host; ** authors used the term 'adults' for the free-swimming stage which exited the fish host; †: toxic to fish; [a] carp/trout/eels/ornamental fish.

Table 2. Management strategies tested against infections of *Ichthyophthirius multifiliis* Fouquet, 1876

(A strategy is regarded as being partially effective if it kills 50–80%, and effective if it kills ⩾80% of the stages under test. Mortality refers to the parasite stages unless otherwise stated.)

Electrotherapy					
In vitro – Trophozoides*					
Electrode type	Volts per 2·5 cm separation	Current	Duration (s)	Efficacy	Reference
Carbon	55–150	150–350	5	Not effective –14·35% mortality after 24 h	Farley and Heckmann (1980)
Carbon	104–150	200–350	5	Not effective –7·09% mortality after 24 h	
Carbon	150		3	Effective – 100% mortality	
Carbon	150		3	Effective – 100% mortality	
Carbon	250		3	Effective – 100% mortality	
Carbon	350		3	Effective – 100% mortality	
Carbon	350		3	Effective – 100% mortality	
Copper	88–115	135–200	5	Effective – 100% mortality after 24 h	
Copper	115	135	5	Effective – 100% mortality after 24 h	
Steel hardware cloth 150–240		160–400	5	Not effective –2·99% mortality after 24 h	
Steel hardware cloth 150		340	5	Not effective –0·87% mortality after 24 h	
Mechanical filtration					
In vitro – protomonts					
Mesh size (μm)	Efficacy				
500	Not effective – 0% protomonts filtered out				Heinecke and Buchmann (2009)
300	Not effective – 6% protomonts filtered out				
160	Not effective – 22% protomonts filtered out				
80	Effective – 100% protomonts filtered out				
Mechanical removal of the tomocysts					
In vitro – protomonts					
Lining surface		Efficacy			
Crystal polysterin		Not effective – 9·8% mortality			Shinn *et al*. (2009)
Polypropylene – based plastic		Effective – 90·2% mortality			
Polyethylene – based plastic		Partially effective – 76·5% mortality			
Chlovar chlorinated rubber		Not effective – 46·6% mortality			
In vivo – commercial raceways in *O. mykiss* hatchery (Suction head + lining of the bottom of the raceways)					
Visit number		Efficacy			
1 (after 2 weeks)		No infection in control and experimental raceways			Shinn *et al*. (2009)
2 (after 4 weeks)		No infection in control and experimental raceways			
3 (after 6 weeks)		Low infection levels in both control and experimental raceways			
4 (after 8 weeks)		Effective – 92% reduction in trophont numbers compared to the control			
5 (after 10 weeks)		Effective – 99% reduction in trophont numbers compared to the control			

(Suction head stopped, only lining of the bottom of the raceways)						
6 (after 12 weeks)					Partially effective – 54% reduction in trophont numbers compared to the control	
UV light						
In vivo- fish species not specified						
Number of UV bulbs used (UV light generated)					Efficacy	
0					Not effective – 82·81% fish mortality	Gratzek *et al*. (1983)
1 (91 900 μW s cm^{-2})					Effective – 1·33% fish mortality	
2 (183 800 μW s cm^{-2})					Effective – 0·7% fish mortality	
Water flow						
In vivo – experimental raceways of *I. punctatus* fingerlings						
Fish density (no. L^{-1})	Flow rate (L min^{-1})	Velocity (cm min^{-1})	Turn-over (no. h^{-1})	Efficacy		
0·33	5		4·1	0·5	Not effective – 100% mortality of infected fish	Bodensteiner *et al*. (2000)
0·25	15		12·2	1·5	Not effective – 52% mortality of infected fish	
0·25	25		20·3	2·5	Effective – 14% mortality of infected fish	
0·33–0·66	5		4·1	0·5	Not effective – 100% mortality of infected fish	
0·33–0·66	25		20·3	2·5	Effective – 9% mortality of treated fish	
0·33–0·66	45		36·5	4·5	Effective – 7% mortality of treated fish	
In vivo – production raceways of *I. punctatus* fingerlings						
0·89–1·29	> 2800		> 85	> 2·1	Effective – no trophonts observed	
0·71–1·40	> 2800		> 85	> 2·1	Effective – no trophonts observed	

Abbreviations: s: seconds, *****authors use the term 'trophozites' for the free-swimming stage which exited the fish host.

REFERENCES

Aihua, L. and Buchmann, K. (2001). Temperature and salinity-dependent development of a Nordic strain of *Ichthyophthirius multifiliis* from rainbow trout. *Journal of Applied Ichthyology* **17**, 173–276.

Alderman, D. J. (1985). Malachite green: a review. *Journal of Fish Diseases* **8**, 289–298.

Balta, F., Kayis, S. and Altinok, I. (2008). External protozoan parasites in three trout species in the Eastern Black Sea region of the Turkey: intensity, seasonality and their treatments. *Bulletin of European Association of Fish Pathologists* **28**, 157–162.

Bisharyan, Y., Chen, Q., Hossain, M. M., Papoyan, A. and Clark, T. G. (2003). Cadmium effects on *Ichthyophthirius*: evidence for metal-sequestration in fish tissues following administration of recombinant vaccines. *Parasitology* **123** (Suppl.) S87–S93.

Bodensteiner, L. R., Sheenan, R. J., Willis, P. S., Brandenburg, A. M. and Lewis, W. M. (2000). Flowing water: an effective treatment for ichthyophthiriasis. *Journal of Aquatic Animal Health* **12**, 209–219.

Boyd, C. E. (1990). *Water Quality In Ponds For Aquaculture*. Alabama Agricultural Experiment Station, Auburn University, Auburn, AL, USA.

Boyd, C. E. (2005). Copper treatment controls phytoplankton. *Global Aquaculture Alliance* **8**, 69–70.

Brown, E. M. and Gratzek, J. B. (1980). *Fish Farming Handbook. Food, Bait, Tropicals and Goldfish*. AVI Publishing Company, Westport, USA.

Bruzio, M. and Buchmann, K. (2010). The effect of peracetic acid products on parasites causing white spot diseases. *Fish Farmer* **33**, 25–27.

Bryce, D. I. M., Croshaw, B., Hall, J. E., Holland, V. R. and Lessel, B. (1978). The activity and safety of the antimicrobial agent bronopol (2-bromo-2-nitropropan-1,3-diol). *Journal of the Society of Cosmetic Chemists* **29**, 3–24.

Buchmann, K. and Bresciani, J. (1997). Parasitic infections in pond-reared rainbow trout *Oncorhynchus mykiss* in Denmark. *Diseases of Aquatic Organisms* **28**, 125–138.

Buchmann, K., Jensen, P. B. and Kruse, K. D. (2003). Effects of sodium percarbonate and garlic extract on *Ichthyophthirius multifiliis* theronts and tomocysts: *In vitro* experiments. *North American Journal of Aquaculture* **65**, 21–24.

Buchmann, K., Bresciani, J. and Jappe, C. (2004). Effects of formalin treatment on epithelial structure and mucous cell densities in rainbow trout, *Oncorhynchus mykiss* (Walbaum), skin. *Journal of Fish Diseases* **27**, 99–104.

Burkart, M. A., Clark, T. G. and Dickerson, H. W. (1990). Immunization of channel catfish, *Ictalurus punctatus* Rafinesque, against *Ichthyophthirius multifiliis* (Fouquet): killed *versus* live vaccines. *Journal of Fish Diseases* **13**, 401–410.

Cardeilhac, P. and Whitaker, B. (1988). Copper treatments: uses and precautions. *Veterinary Clinics of North America* **18**, 435–448.

Colorni, A., Ullal, A., Heinisch, G. and Noga, E. J. (2008). Activity of the antimicrobial polypeptide piscidin 2 against fish ectoparasites. *Journal of Fish Diseases* **31**, 423–432.

Cross, D. G. (1972). A review of the methods to control ichthyophthiriasis. *Progressive Fish Culturist* **34**, 165–170.

Culp, S. J. (2004). NTP technical report on the toxicity studies on malachite green chloride and leucomalachite green administered in feed to F344/N rats and B6C3F1 mice. US Department of Health and Human Services June 2004. National Toxicology Program, Toxicity report series. NIH Publication No. 04-4416.

Culp, S. J. and Beland, F. A. (1996). Malachite green: a toxicological review. *Journal of American College Toxicology* **15**, 219–238.

Deilhac, P. and Whitaker, B. (1988). Copper treatments: uses and precautions. *Veterinary Clinics of North America* **18**, 435–448.

Dickerson, H. W. (2006). *Ichthyophthirius multifiliis* and *Cryptocaryon irritans* (Phylum Ciliophora) In *Fish Diseases and Disorders, Vol. 1: Protozoan and Metazoan infections* (ed. Woo, P. T. K.), pp. 116–153. CAB International, Cambridge, MA, USA.

Dolezelova, P., Macova, S., Plhalova, L., Pistekova, V., Svobodova, Z., Bedanova, I. and Voslarova, E. (2009). Comparison of the sensitivity of different fish species to medical substances. *Neuroendocrinology Letters* **30**, 248–52.

Duffort, G., Houeix, N., Manier, N. and Troise, A. (2010). Institut National de l'EnviRonnement Industriel et des risSques (INERIS)- Fiche de donnees toxicologiques et environnementales des substances chimiques. Formaldéhyde. INERIS.

Ekamen, A. P., Obiekezie, A., Kloas, W. and Knopf, K. (2004). Effects of crude extracts of *Mucuna pruriens* (Fabaceae) and *Carica papaya* (Caricaceae) against the protozoan fish parasite *Ichthyophthirius multifiliis*. *Parasitology Research* **92**, 361–366.

Elsayed, E. E., El Dien, N. E. and Mahmoud, M. A. (2006). Ichthyophthiriasis: various fish susceptibility or presence of more than one strain of the parasite? *Nature and Science* **4**, 5–13.

Ewing, M. S., Kocan, K. M. and Ewing, S. A. (1983). *Ichthyophthirius multifiliis*: morphology of the cyst wall. *Transactions of the American Microscopical Society* **102**, 122–128.

Fallang, A., Ramsay, J. M., Sevatdal, S., Burka, J. F., Jewess, P., Hammell, K. L. and Horsbergs, T. E. (2004). Evidence for occurrence of an organophosphate-resistant type of acetylcholinesterase in strains of sea lice (*Lepeophtheirus salmonis* Krøyer). *Pest Management Science* **60**, 1163–1170.

Farley, D. G. and Heckmann, R. (1980). Attempts to control *Ichthyophthirius multifiliis* Fouquet (Ciliophora: Orphryoglnidae) by chemotherapy and electrotherapy. *Journal of Fish Diseases* **3**, 203–212.

From, J., Karas, N. and Vordermeier, T. (1992). Trials with toltrazuril against *Ichthyophthirius multifiliis* Fouquet, 1876. *Bulletin of European Association of Fish Pathologists* **12**, 137–138.

Gaikowski, M. P., Densmore, C. L. and Blazer, V. S. (2009). Histopathology of repeated, intermittent exposure of chloramine-T to walleye (*Sander vitreum*) and (*Ictalurus punctalus*) channel catfish. *Aquaculture* **287**, 28–34.

Garcia, L., Becker, A. G., Copatti, C. E. and Baldisserotto, B. (2007). Salt in food and water as a supportive therapy of *Ichthyophthirius multifiliis* infestation on silver catfish, *Rhamdia quelen*, fingerlings. *Journal of World Aquaculture Society* **38**, 1–11.

Goodwin, A. E. and Straus, D. L. (2006). Solid and liquid formulations of copper sulphate: efficacy at high and low alkalinities. *North American Journal of Aquaculture* **68**, 359–363.

Gratzek, J. B., Gilbert, J. P., Lohr, A. L., Shotts, E. B. and Brown, J. (1983). Ultraviolet light control of *Ichthyophthirius multifiliis* Fouquet in a closed fish culture recirculation system. *Journal of Fish Diseases* **6**, 145–153.

Guest, C. W. (1983). Control of *Ichthyophthirius* in peacock bass fingerlings. *Progressive Fish Culturist* **45**, 57.

Heinecke, R. D. and Buchmann, K. (2009). Control of *Ichthyophthirius multifiliis* using a combination of water filtration and sodium percarbonate: dose-response studies. *Aquaculture* **288**, 32–35.

Henderson, A. L., Schmitt, T. C., Heinze, T. M. and Cerniglia, C. E. (1997). Reduction of malachite green to leucomalachite green by intestinal bacteria. *Applied Environmental Microbiology* **63**, 4099–4101.

Herber, T. (2009). Organic compounds used in aquaculture. In *Hormones and Pharmaceuticals Generated by Concentrated Animal Feeding Operations, Emerging Topics in Ecotoxicology 1* (ed. Shore, L. S. and Pruden, A.), pp. 95–120. Springer Science and Business Media, New York, USA.

Herwig, N. (1979). *Handbook of Drugs and Chemicals used in the Treatment of Fish Diseases*. Charles C. Thomas Publisher, Springfield, USA.

Heuer, O. E., Kruse, H., Grave, K., Collignon, P., Karunasagar, I. and Angulo, F. J. (2009). Human health consequences of use of antimicrobial agents in aquaculture. *Clinical Infectious Diseases* **49**, 1248–1253.

Hines, R. S. and Spira, D. T. (1974). Ichthyophthiriasis in the mirror carp *Cyprinus carpio* L. V. Acquired immunity. *Journal of Fish Biology* **6**, 373–378.

Hoffman, G. L. and Meyer, F. P. (1974). *Parasites of Freshwater Fishes. A Review of their Control Treatment*. TFH Publication, Inc Neptune City, USA.

Hohreiter, D. W. and Rigg, D. K. (2001). Derivation of ambient water quality criteria for formaldehyde. *Chemosphere* **45**, 471–486.

Jensen, P. B., Kruse, K. D., Kristensson, R. T. and Buchmann, K. (2001). The effect of sodium percabonate (BioCare SPC) on *Ichthyophthirius multifiliis* and *Gyrodactylus i*n rainbow trout. *Biomar Newsletter* **3**, 2.

Jørgensen, T. R., Larsen, T. B. and Buchmann, K. (2009). Parasite infections in recirculated rainbow trout (*Oncorhynchus mykiss*) farms. *Aquaculture* **289**, 91–94.

Johnson, M. D. and Sharma, K. D. (1999). Kinetic and mechanism of the reduction of ferrate by one-electron reductants. *Inorganica Chimica Acta* **293**, 229–233.

Kayis, S., Ozcelep, T., Capkin, E. and Altinok, I. (2009). Protozoan and metazoan parasites of cultured fish in Turkey and their applied treatments. *The Israeli Journal of Aquaculture* **61**, 93–102.

Kurovskaya, L. Y. (2005). Effect of violet C antiseptic on the numbers of ectoparasites and some physiological and biochemical indices of carps. *Hydrobiological Journal* **41**, 95–102.

Lauridsen, J. H. and Buchmann, K. (2010). Effects of short and long-term glucan feeding of rainbow trout (Salmonidae) on the susceptibility to *Ichthyophthirius multifiliis* infections. *Acta Ichthyologica et Piscatoria* **40**, 61–66.

Lahnsteiner, F. and Weismann, T. (2007). Treatment of ichthyophthiriasis in rainbow trout and common carp with common and alternative therapeutics. *Journal of Aquatic Animal Health* **19**, 186–194.

Lees, F., Baillie, M., Gettinby, G. and Revie, C. W. (2008). The efficacy of emamectin benzoate against infestations of *Lepeophtheirus salmonis* on farmed Atlantic salmon (*Salmo salar* L.) in Scotland, 2002–2006. *PLoS ONE* **3**, e1549.

Ling, F., Luo, Q., Wang, J. L., Wang, Y. P., Wang, W. B. and Gong, X. N. (2009). Effects of the 'all-fish' GH (growth hormone) transgene expression on resistance to *Ichthyophthirius multifiliis* infections in common carp, *Cyprinus carpio* L. *Aquaculture* **292**, 1–5.

Ling, F., Wang, J. G., Liu, Q. F., Li, M., Ye, L. T. and Gong, X. N. (2010). Prevention of *Ichthyophthirius multifiliis* infestation in goldfish (*Carassius auratus*) by postassium ferrate (VI) treatment. *Veterinary Parasitology* **168**, 212–216.

Ling, K. H., Sin, Y. M. and Lam, T. J. (1993). Effect of copper sulfate on ichthyophthiriasis (white spot disease) in goldfish (*Carassius auratus*). *Aquaculture* **118**, 23–25.

Lom, J. and Dyková, I. (1992). *Protozoan Parasites of Fishes*. *Developments in Aquaculture and Fisheries Science, Vol. 26*. Elsevier, Amsterdam.

Luzardo-Álvarez, A., Martínez-Mazagatos, J., Santamarina-Fernández, M. T., Otero-Espinar, F. J. and Blanco-Méndez, J. (2003). Oral pharmacological treatments for *Ichthyophthirius* of rainbow trout (*Oncorhynchus mykiss*). *Aquaculture* **220**, 15–25.

Ma, J. and Liu, W. (2002). Effectiveness and mechanism of potassium ferrate (VI) preoxidation for algae removal by coagulation. *Water Research* **36**, 871–878.

Matthews, R. A. (1994). *Ichthyophthirius multifiliis* Fouquet, 1876: infection and proactive response within the fish host. In *Parasitic Diseases of Fish* (ed. Pike, A. W. and Lewis, J. W.), Samara Publishing Ltd., Dyfed.

Matthews, R. A. (2005). *Ichthyophthirius multifiliis* Fouquet and ichthyophthiriosis in freshwater teleosts. *Advances in Parasitology* **59**, 159–241.

Mehlhorn, H., Schmahl, G. and Heberkorn, A. (1988). Toltrazuril effective against a broad spectrum of protozoan parasites. *Parasitology Research* **75**, 64–66.

Meinelt, T., Pietrock, M., Burnison, K. and Steinberg, C. (2005). Formaldehyde toxicity is altered by calcium and organic matter. *Journal of Applied Ichthyology* **21**, 121–124.

Meinelt, T., Matzke, S., Stüber, A., Pietrock, M., Wienke, A., Mitchell, A. J. and Straus, D. L. (2009). Toxicity of peracetic acid (PAA) to tomonts of *Ichthyophthirius multifiliis*. *Diseases of Aquatic Organisms* **86**, 51–56.

Mifsud, C. and Rowland, S. J. (2008). Use of salt to control ichthyophthiriosis and prevent saprolegniosis in silver perch, *Bidyanus bidyanus*. *Aquaculture Research* **39**, 1175–1180.

Miron, D. S., Silva, L. V. F., Golombieski, J. I. and Baldisserotto, B. (2003). Efficacy of different salt (NaCl) concentrations in the treatment of *Ichthyophthirius multifiliis*-infected silver catfish, *Rhamdia quelen*, fingerlings. *Journal of Applied Aquaculture* **14**, 155–161.

Moore, J. M. (2005). Comparison of copper toxicity to channel catfish, *Ictalurus punctatus*, and blue catfish, *I. furcatus*, fingerlings. *Journal of Applied Aquaculture* **17**, 77–84.

Noble, A. C. and Summerfelt, S. T. (1996). Diseases encountered in rainbow trout cultured in recirculating systems. *Annual Review of Fish Diseases* **6**, 65–92.

Noga, E. J. (2010). *Fish Disease: Diagnosis and Treatment*. Wiley-Blackwell.

Novartis (2002). Pyceze: Technical dossier. Information for Farmers. Novartis Animal Vaccines. UK.

Pedersen, L. F., Pedersen, P. B., Nielsen, J. L. and Nielsen, P. H. (2009). Peracetic acid degradation and effects on nitrification in recirculating aquaculture systems. *Aquaculture* **296**, 246–254.

Picón-Camacho, S. M., Taylor, N. G. H., Bron, J. E., Guo, F. C. and Shinn, A. P. (2011*a*). Effects of continuous exposure to low doses of bronopol on the infection dynamics of *Ichthyophthirius multifiliis* (Ciliophora), parasitising rainbow trout (*Oncorhynchus mykiss* Walbaum). *Veterinary Parasitology* (in the Press).

Picón-Camacho, S. M., Marcos-Lopez, M., Beljean, A., Debeaume, S. and Shinn, A. P. (2011*b*). *In vitro* assessment of the chemotherapeutic action of a specific hydrogen peroxide, peracetic and peroctanoic acid based formulation against the free-living stages of *Ichthyophthirius multifiliis* (Ciliophora). *Parasitology Research*.

Pieters, N., Brunt, J., Austin, B. and Lyndon, A. R. (2008). Efficacy of in-feed probiotics against *Aeromonas bestiarum* and *Ichthyophthirius multifiliis* skin infections in rainbow trout (*Oncorhynchus mykiss*, Walbaum). *Journal of Applied Microbiology* **105**, 723–732.

Pillay, T. V. R. and Kutty, M. N. (2005). *Aquaculture: Principles and Practices*. Blackwell Publishing, Oxford.

Post, G. and Vesely, K. R. (1983). Administration of drugs by hyper-osmotic or vacuum infiltration or surfactant immersion ineffective for control of intradermally encysted *Ichthyophthirius multifiliis*. *Progressive Fish Culturist* **45**, 164–166.

Pottinger, T. G. and Day, J. G. (1999). A *Saprolegnia parasitica* challenge system for rainbow trout: assessment of Pyceze as an anti-fungal control agent for both fish and ova. *Diseases of Aquatic Organisms* **36**, 129–141.

Powell, M. and Harris, J. (2004). Influence of oxygen on the toxicity of chloramine-T to Atlantic salmon smolts in freshwater and seawater. *Journal of Aquatic Animal Health* **16**, 83–92.

Rábago-Castro, J. L., Sanchez, J. G., Pérez-Castaneda, R. and González-González, A. (2006). Effects of the prophylactic use of Romet®-30 and copper sulfate on growth, condition and feeding indices in channel catfish (*Ictalurus punctatus*). *Aquaculture* **253**, 343–349.

Rahkonen, R. and Koski, P. (2002). Post malachite green: alternative strategies for fungal infections and white spot disease. *Bulletin of European Association of Fish Pathologists* **22**, 152–157.

Rapp, J. (1995). Treatments of rainbow trout (*Oncorhynchus mykiss* Walb.) fry infected with *Ichthyophthirius multifiliis* by oral administration of dimetrazole. *Bulletin of European Association of Fish Pathologists* **15**, 67–69.

Rintamäki-Kinnunen, P. and Valtonen, E. T. (1997). Epizootiology of protozoans in farmed salmonids in northern latitudes. *International Journal of Parasitology* **27**, 89–99.

Rintamäki-Kinnunen, P., Rahkonen, M., Mannermaa-Keränen, A. L., Suomalainen, L. R., Mykrä, H. and Valtonen, E. T. (2005*a*). Treatment of ichthyophthiriasis after malachite green. I. Concrete tanks at salmonid farms. *Diseases of Aquatic Organisms* **64**, 69–76.

Rintamäki-Kinnunen, P., Rahkonen, M., Mykrä, H. and Valtonen, E. T. (2005*b*). Treatment of ichthyophthiriasis after malachite green. II. Earth ponds at salmonids farms. *Diseases of Aquatic Organisms* **66**, 15–20.

Rowland, S. J., Misfud, C., Nixon, M., Read, P. and Landos, M. (2009). Use of formalin and copper to control ichthyophthiriosis in the Australian freshwater fish silver perch (*Bidyanus bidyanus* Mitchell). *Aquaculture Research* **40**, 44–54.

Ruider, S., Schmal, G., Mehlhorn, H., Scmidt, H. and Ritter, G. (1997). Effects of different malachite green derivates and metabolites on the fish ectoparasite, *Ichthyophthirius multifiliis*, Fouquet 1876 (Hymenostomatida, Ciliophora). *European Journal of Protistology* **33**, 375–388.

Sanabria, C., Diamant, A. and Zilberg, D. (2009). Effects of commonly used disinfectants and temperature on swim bladder non-inflation in freshwater angelfish, *Pterophyllum scalare* (Lichtenstein). *Aquaculture* **292**, 158–165.

Schmidt, L. J., Gaikowski, M. P. and Gingerich, W. H. (2006). Environmental Assessment for the Use of Hydrogen Peroxide in Aquaculture for Treating External Fungal and Bacterial Diseases of Cultured Fish and Fish Eggs. USGS. Science for a Changing World. pp. 180.

Schlenk, D., Gollon, J. L. and Griffin, B. R. (1998). Efficacy of copper sulfate for the treatment of ichthyophthiriasis in channel catfish. *Journal of Aquatic Animal Health* **10**, 390–396.

Schlotfeld, H. J. (1993). Chemikalien zur therapie bei nutzfischen nun zugelassen! Standard-Zulassungen. *Fisch Teichwirt* **12**, 421–424.

Schlotfeld, H. J. (1998). Therapienotstand bei fischen in der Bundesrepublik Deutschland. *Fisch Teichwirt* **2**, 42–47.

Schmahl, G., Mehlhorn, H. and Taraschewski, H. (1989). Treatment of fish parasites. 5. The effects of sym. triazinone (toltrazuril) on fish parasitic Ciliophora (*Ichthyophthirius multifiliis* Fouquet, 1876, *Apiosoma amoebea* Grenfell, 1884, *Trichodina* sp. Ehrenberg, 1831). *European Journal of Protistology* **24**, 152–161.

Schmahl, G., Schmidt, H. and Ritter, G. (1996). The control of ichthyopthiriasis by a medicated food containing quinine: efficacy test and ultrastructure investigations. *Parasitology Research* **82**, 697–705.

Schnick, R. A. (1988). The impetus to register new therapeutants for aquaculture. *Progressive Fish Culturist* **50**, 190–196.

Selosse, P. M. and Rowland, S. J. (1990). Use of common salt to treat ichthyophthiriasis in Australian warm water fishes. *Progressive Fish Culturist* **52**, 124–127.

Shinn, A., Wootten, R., Sommerville, C. and Conway, D. (2001). Putting the squeeze on whitespot. *Trout News* **32**, 20–25.

Shinn, A. P., Wootten, R. and Sommerville, C. (2003a). Alternative compounds for the treatment of *Ichthyophthirius multifiliis* infecting rainbow trout. *Trout News* **35**, 38–41.

Shinn, A. P., Wootten, R., Côte, I. and Sommerville, C. (2003*b*). Efficacy of selected oral chemotherapeutants against *Ichthyophthirius multifiliis* (Ciliophora: Ophyroglenidae) infecting rainbow trout *Oncorhynchus mykiss*. *Diseases of Aquatic Organisms* **55**, 17–22.

Shinn, A., Taylor, N. and Wootten, R. (2005). Development of a management system for the control of *Ichthyophthirius multifiliis*. *Trout News* **40**, 21–25.

Shinn, A. P., Picón-Camacho, S. M., Bawden, R. and Taylor, N. G. H. (2009). Mechanical control of *Ichthyophthirius multifiliis* Fouquet, 1876 (Ciliophora) in a rainbow trout hatchery. *Aquaculture Engineering* **41**, 152–157.

Shinn, A. P., Picón-Camacho, S. M., Bron, J. E., Conway, D., Yoon, G. H., Guo, F. C. and Taylor, N. G. H. (2011). The anti-protozoal activity of bronopol on the key life-stages of *Ichthyophthirius multifiliis* Fouquet, 1876 (Ciliophora). *Veterinary Parasitology* (in press).

Sommerset, I., Krossøy, B., Biering, E. and Frost, P. (2005). Vaccines for fish in aquaculture. *Expert Reviews of Vaccines* **4**, 89–101.

Straus, D. L. and Griffin, B. R. (2001). Prevention of an initial infestation of *Ichthyophthirius multifiliis* in channel catfish and blue tilapia by potassium permanganate treatment. *North American Journal of Aquaculture* **63**, 11–16.

Srivastava, S., Sinha, R. and Roy, D. (2004). Toxicological effects of malachite green. *Aquatic Toxicology* **66**, 319–329.

Straus, D. L. and Griffin, B. R. (2002). Efficacy of potassium permanganate in treating ichthyophthiriasis in channel catfish. *Journal of Aquatic Animal Health* **14**, 145–148.

Straus, D. L. (1993). Prevention of *Ichthyophthirius multifiliis* infestation in channel catfish fingerlings by copper sulfate treatment. *Journal of Aquatic Animal Health* **5**, 152–154.

Straus, D. L. (2008). Comparison of copper sulphate concentrations to control ichthyophthiriasis in fingerling channel catfish. *Journal of Applied Aquaculture* **20**, 272–284.

Straus, D. L. and Meinelt, T. (2009). Acute toxicity of peracetic acid (PAA) formulations to *Ichthyophthirius multifiliis* theronts. *Parasitology Research* **104**, 1237–1241.

Straus, D. L., Hossain, M. M. and Clark, T. G. (2009). Strain differences in *Ichthyophthirius multifiliis* to copper toxicity. *Diseases of Aquatic Organisms* **83**, 31–36.

Sudová, E., Straus, D. L., Wienke, A. and Meinelt, T. (2010). Evaluation of continuous 4-day exposure to peracetic acid as a treatment for *Ichthyophthirius multifiliis*. *Parasitology Research* **106**, 539–542.

Swennes, A. G., Findly, R. C. and Dickerson, H. W. (2007). Cross-immunity and antibody responses to different immobilisation serotypes of *Ichthyophthirius multifiliis*. *Fish Shellfish Immunology* **22**, 589–597.

Tieman, D. M. and Goodwin, A. E. (2001). Treatments of ich infestations in channel catfish evaluated under static and flow-through water conditions. *North American Journal of Aquaculture* **63**, 293–299.

Tojo, J. L., Santamarina, M. T., Ubeira, F. M., Leiro, J. and Sanmartin, M. L. (1994). Trials for the control of ichthyophthiriosis in rainbow trout (*Oncorhynchus mykiss*). *Bulletin of European Association of Fish Pathologists* **14**, 148–152.

Tojo-Rodriguez, J. L. and Santamarina-Fernandez, M. T. (2001). Attempts at oral pharmacological treatment of *Ichthyophthirius multifiliis* in rainbow trout, *Oncorhynchus mykiss* (Walbaum). *Journal of Fish Diseases* **24**, 249–252.

Tokşen, E. and Nemli, E. (2010). Oral treatment trials on telescope fish (*Carassius auratus*) experimentally infected with *Ichthyophthirius multifiliis* (Fouquet, 1876). *Bulletin of European Association of Fish Pathologists* **30**, 48–52.

Treves-Brown, K. M. (2000). *Applied Fish Pharmacology*. Kluwer Academic Publishers, Dordrecht.

Tucker, C. S. (1987). Acute toxicity of potassium permanganate to channel catfish fingerlings. *Aquaculture* **60**, 93–98.

Ullal, A. J., Litaker, R. W. and Noga, E. J. (2008). Antimicrobial peptides derived from haemoglobin are expressed in epithelium of channel catfish (*Ictalurus punctatus*, Rafinesque). *Developmental and Comparative Immunology* **32**, 1301–1312.

Ullal, A. J. and Noga, E. J. (2010). Antiparasitic activity of the antimicrobial pepetide HbβP-1, a member of the β-haemoglobin peptide family. *Journal of Fish Diseases* **33**, 657–664.

Valtonen, E. T. and Koskivaara, M. (1994). Relationships between the parasites of some wild and cultured fishes in two lakes and a fish farm in central Finland. *International Journal of Parasitology* **24**, 109–118.

Wagner, G. (1960). Der Entwicklungszyklus von *Ichthyophthirius multifiliis* Fouquet und der Einfluss physikalischer und chemischer aussenfaktoren. *Zeitschrift Fisherei* **9**, 425–443.

Wahli, T., Streiff, K. and Meier, W. (1985). Influence of ascorbic acid on *Ichthyophthirius multifiliis* infections in trout. *Bulletin of European Association of Fish Pathologists* **4**, 86–87.

Wahli, T., Schmitt, M. and Meier, W. (1993). Evaluation of alternatives to malachite green oxalate as a therapeutant for ichthyopthirius in ranbow trout, *Oncorhynchus mykiss*. *Journal of Applied Ichthyology* **9**, 237–249.

Wahli, T., Frischknecht, R., Schmitt, M., Gabaudan, J., Verlhac, V. and Meier, W. (1995). A comparison of the effect of silicone coated ascorbic acid and ascorbyl phosphate on the course of ichthyophthiriosis in rainbow trout, *Oncorhynchus mykiss* (Walbaum). *Journal of Fish Diseases* **18**, 347–355.

Wahli, T., Verlhac, V., Gabaudan, J., Schüep, W. and Meier, W. (1998). Influence of combined vitamins C and E on non-specific immunity and diseases resistance of rainbow trout, *Oncorhynchus mykiss* (Walbaum). *Journal of Fish Diseases* **21**, 127–137.

Wooster, G. A., Martinez, C. M. and Bowser, P. R. (2005). Human health risks associated with formalin treatments used in aquaculture: Initial study. *North American Journal of Aquaculture* **67**, 111–113.

World Health Organization, International Agency for Research on Cancer (2006). *Formaldehyde, 2- butoxyethanol and 1-tert-butoxypropan-2-ol*. IARC monographs on the evaluation of carcinogenic risks to humans Volume 88. World Health Organization, International Agency for Research on Cancer, Lyon.

Xu, D. H., Schoemaker, C. A. and Klesius, P. H. (2008). Effect of tricaine methanesulfonate on survival and reproduction of the fish ectoparasite *Ichthyophthirius multifiliis*. *Parasitology Research* **103**, 979–982.

Yao, J. Y., Shen, J. Y., Li, X. L., Xu, Y., Hao, G. J., Pan, X. Y., Wang, G. X. and Yin, W. L. (2010). Effect of sanguinarine from the leaves of *Macleaya cordata* against *Ichthyophthirius multifiliis* in grass carp (*Ctenopharyngodon idella*). *Parasitology Research* **107**, 1035–1042.