Current disease treatments for the ornamental pet fish trade and their associated problems

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Abstract

The trade in live ornamental fishes to be held as companion animals or displayed in public aquaria has an estimated global annual value of US$15-20 billion. Supply chains for ornamental pet fishes often involve many more parties than for fish farmed as food fishes, and at each stage fishes are exposed to stressors including handling, confinement, crowding, mechanical disturbance, and poor water quality. If chronic, these stressors can compromise their immune system, making fishes more susceptible to pathogens. Mortality and morbidity from infectious disease can result in considerable welfare impacts and massive economic losses for the industry, and the range of infective agents seen in ornamental species is well documented. However, treating these diseases is not straightforward with practices varying greatly across the trade and with several approaches having unintended consequences, such as the emergence of resistant strains of pathogens. While disease treatments for a handful of fish species (e.g. koi, goldfish) have received focused research attention, for the home aquarium owner, there is an increasing reliance on products based on natural compounds which have received far less scientific attention. This review aims to highlight the gaps in our knowledge surrounding the range of disease treatments used across the ornamental pet fish trade, with a particular focus on freshwater tropical species destined for home aquaria. Consideration is given to the potential problems arising from these treatments, including microbial resistance and effects of treatments themselves on fish health and welfare.

Key words: home aquaria; bacteria; freshwater tropical fish; antimicrobial resistance; welfare; medicines.

Introduction

The trade in live ornamental fishes to be held as companion animals, and their associated products, represents an economically important global industry. In the UK alone, the industry is valued at ~£400 million (King, 2019) with the vast majority of this trade in tropical freshwater species with > 4500 species comprising 90% of the market (Iqbal and Shalij, 2019; King, 2019; OATA, 2020). The global ornamental industry relies on transnational supply chains to provide fish keepers in countries such as the UK, USA and Germany, with fish reared/collected from nations such as Singapore, Israel, and Japan (OATA, 2018; Olivier, 2003). These supply chains involve many parties including importers, exporters, distributors, wholesalers, and retailers. At each stage in the supply chain, fishes can be exposed to a variety of stressors which can result in mortality (Jones et al., 2021). These stressors include handling, confinement and crowding (Barton and Iwama, 1991), mechanical disturbance during transit (Masud et al., 2019), poor water quality, accumulation of toxic waste products, and reduction in dissolved oxygen (Sampaio and Freire, 2016). Exposure to stressors over a period of time can compromise the immune system of the fish making them more susceptible to bacterial diseases (Eslamloo et al., 2014). In addition to the effects of long-term stress on the immune system, fishes are routinely netted for grading or preparing for transport which can result in loss or damage to the epidermal mucus layer that protects fishes against pathogens (Fouz et al., 1990; Raj et al., 2011).

Susceptibility to disease is therefore a major challenge for the ornamental pet fish trade and is the second most frequent cause of ornamental fish mortality and morbidity, after collective water quality issues (Lewbart, 2001). These mortalities result in economic losses for the ornamental fish industry (Cardoso et al., 2021) and an overreliance on antibiotics has fostered resistant strains of pathogens (Weir et al., 2012). However, treating these diseases is not straightforward, and research has focused primarily on one or two species. Although the majority (95%) of freshwater pet fishes are tropical, research into ornamental fish diseases is most advanced for cyprinid species (e.g. goldfish, koi) where development of a vaccine for koi herpesvirus disease looks promising for the industry (Klafack et al., 2022). However, for small freshwater ornamentals, destined for lives in home aquaria, far less scientific consideration has been given and more effective treatments are needed to prevent disease. In many importing countries, there is an increasing reliance by home aquarists on products based on natural compounds, potentially due to their perceived environmental sustainability (Arapi and Cable, unpublished data). However, these disease treatments have generally been overlooked within the scientific literature and their efficacy and effects on general fish health and welfare are under-researched.

Here we review disease management strategies within the freshwater ornamental fish trade with a particular focus on tropical species destined for home aquaria. We look first at more traditional approaches such as the use of antibiotics and the emergence of antimicrobial resistance. In the second part of this review, we present a systematic review of information available on treatments available to home aquarists highlighting the gaps in our knowledge surrounding the range of disease treatments used across the ornamental fish trade and areas for future research.

Diseases in ornamental fishes

Infectious diseases cause significant mortalities to stocks of ornamental fishes, including in aquaculture and research facilities, sometimes resulting in cumulative mortalities >50% (Hawke et al., 2013; Kumar et al., 2015). Cyprinid herpesviruses 2 and 3, are particularly damaging to koi and goldfish farms respectively, with outbreaks across Asia causing mortalities as high as 95% (Dharmaratnam et al., 2018; Jiang et al., 2020; Piewbang et al., 2024). While these outbreaks are undoubtedly costly to the industry, data on the direct economic impact of infectious diseases within the ornamental trade is sparse, not least as there are few incentives for fish farmers to report disease outbreaks in countries without a legal obligation to do so, and where reputational damage could occur.

Ornamental fishes are susceptible to infection by a plethora of microorganisms including metazoa, protozoa, bacteria, algae, fungi, and viruses. Many diseases are caused by Gram negative bacteria which are ubiquitous within ornamental fish holding water and can opportunistically infect immunocompromised individuals (Roberts et al., 2009; Smith et al., 2012). There is considerable overlap in the environment favoured by many ornamental fish species and that required for bacterial growth (e.g. warm temperatures, high concentrations of nutrients, and good oxygenation) (Gomez et al., 2013; Smith et al., 2012). There are also some notable protozoan and fungal-like diseases that commonly occur when the immune system of ornamental fishes is compromised. While viral diseases are an issue for ornamental fishes, prevention of viral diseases generally relies on maintaining virus-free breeding stocks, vaccination where available, and good biosecurity including disinfecting setups between production cycles, UV sterilization of water, and implementation of sufficient quarantine periods (Cardoso et al., 2019). There is an extensive literature on koi herpesvirus disease (KHVD) and a commercial vaccine available in some countries (Klafack et al., 2022). However, for the majority of tropical freshwater fish that are traded to the home aquarium owner, there are no commercial chemical treatments for viruses, therefore viruses are not explored in great detail here.

Bacterial diseases

Gram-negative bacteria known to cause disease issues in ornamental fishes include *Flavobacterium columnare* (columnaris disease), *Edwardsiella* spp., *Aeromonas* spp. (koi ulcerative disease and motile aeromonad disease), *Pseudomonas* spp. (pseudomoniasis), and *Vibrio* spp. (vibriosis). While there are other examples, these five bacteria are particularly significant for the ornamental trade; the symptoms of the diseases they cause are summarised in Table 1. There are comparatively fewer Gram-positive bacterial diseases reported within ornamental fishes; the two main Gram-positive bacteria infecting ornamental fishes held in home aquaria are *Streptococcus* spp. (streptococcosis) and *Nocardia* spp. (nocardiosis). *Mycobacterium* spp. (mycobacteriosis) and *Nocardia* spp. can appear weakly Gram-positive but also presents as an acid-fast bacterium.

Many of the bacteria summarised in Table 1 can cause tail/fin rot in fishes (Emany et al., 1995; Sasmal et al., 2004). This occurs when bacteria colonise the fin tissue and cause necrosis and degeneration, often unevenly, giving the fins a ragged appearance (Lewbart, 2001; Roberts et al., 2009). Poor water quality and fin damage due to aggression or inappropriate handling can predispose fishes to fin rot (Rao et al., 2013). In severe cases, the fin can be significantly reduced, and the infection can progress to the body surface (Chatterjee et al., 2020; Rao et al., 2013). Fin rot can compromise the commercial value of ornamental fishes destined for home aquaria, particularly in species prized for their long flowy fins e.g., fighting fish, *Betta splendens*.

Parasitic diseases

There are numerous parasites, which present considerable economic and welfare-related concerns to the ornamental industry from a diverse range of taxa including protists, monogeneans and crustaceans (Evans and Lester, 2001; Florindo et al., 2017; Iqbal and Haroon, 2014). Some common parasites for pet fishes are *Piscinoodinium* spp. (freshwater velvet disease), *Icthyophthirius multifiliis* (white spot disease), skin and gill flukes (*Gyrodactylus* and *Dactylogyrus* spp.), and roundworms (e.g. *Camallanus* and *Capillaria* spp.). Freshwater velvet disease is caused by the dinoflagellates *Piscinoodinium* sp. which have a direct life cycle with three stages lasting between 4 and 15 days (Lieke et al., 2020; Noga, 2010). Stage one is a free-swimming dinospore which attaches to the epithelium of the host's skin or gills with a specialised extension known as a rhizoid. Once attached, the dinospores become trophonts (feeding stage) which actively parasitise upon the host's cells. Finally, the trophonts detach, encapsulate themselves, and turn into tomonts (reproductive stage) (Lieke et al., 2020). White spot disease, caused by the ciliate *Ichthyophthirius multifiliis,* is arguably one of the most common parasitic diseases of ornamental fishes (Iqbal and Haroon, 2014; Matthews, 2005) and if not treated promptly, can result in high mortalities (Ekanem et al., 2004; Ezz EI Dien et al., 1998; Francis-floyd et al., 2016). Motile theronts (infective stages) of this parasite burrow into the epithelial tissues of the skin, fins, or gills of the host fish where they transform into spherical trophonts (feeding stage) and feed on the surrounding tissue (Dickerson, 2011). Two genus of fluke (monogenean) which are particularly prevalent in the ornamental fish industry are *Gyrodactylus* and *Dactylogyrus.* The former reproduces viviparously while the latter are oviparous (Scott, 1982; Zhang et al., 2022). Regardless of reproductive method, they have direct life cycles and relatively short generation times leading to rapid transmission between host fish (Zhang et al., 2022). Using specialised hooks they attach to the external body surfaces including skin, fins, and gills (favoured by *Dactylogyrus* spp.) feeding off the mucus and epithelial cells of the host (Cable et al., 2002; Said, 2008). In terms of endoparasites of ornamental fishes, perhaps the most significant are nematodes, specifically *Camallanus* and *Capillaria* spp. Both species are similar in clinical presentation, both targeting the gastrointestinal tract of the host fish (Palmeiro and Roberts, 2012). However, *Capillaria* spp. have a direct life cycle whereas *Camallanus* spp. typically uses an intermediate copepod host, although they have exhibited flexibility in this regard directly infecting fish (De, 1999; Levsen, 2001; Palmeiro and Roberts, 2012).

‘Fungal-like’ diseases

Aside from microsporidian parasites, diseases caused by ‘true’ fungal pathogens of fishes are relatively rare (Noga, 2010); although rare *Aspergillus, Rizopus,* and *Mucor* have been reported to cause disease within ornamental fishes (Haroon et al., 2014; Iqbal and Sajjad, 2013). Of the microsporidia, two species commonly infect pet fishes - *Psuedoloma neurophilia* and *Pleistophora hyphessobryconis,* the latter being the causative agent of “neon tetra disease”, despite being nonspecific to neon tetras and infecting a broad range of fish species (Kent and Sanders, 2020; Sanders et al., 2010). These diseases present a particular problem for zebrafish used as model organisms, as they often have subclinical effects on behaviour which can confound interpretation of behavioural endpoints (Estes et al., 2021; Kent and Sanders, 2020; Midttun et al., 2020). For fish destined for ornamental purposes, these diseases represent less concern, typically resulting in subclinical effects with mortality only in some chronic cases (Kent and Sanders, 2020; Sanders et al., 2020). Additionally, there is no proven treatment for either pathogen with evaluation of treatment options in its infancy and current guidance to euthanise severely infected fishes (Lavin et al., 2023). Therefore, these diseases are not considered further here.

Diseases caused by the fungal-like oomycetes or ‘water moulds’ (e.g. *Saprolegnia*, *Achyla*, and *Dictyuchus* spp. etc.) are relatively common in freshwater fishes in part due to their low host specificity (Gozlan et al., 2014). They are ubiquitous within aquatic environments and typically cause secondary infections, opportunistically infecting lesions caused by parasitic or bacterial diseases (Noga, 2010). Alternatively, they can infect hosts by colonising physical trauma caused by aggression or inappropriate handling (Khoo, 2000). Poor water quality and stressors such as crowding and unsuitably low temperatures seem to increase the likelihood of infection (Howe and Stehly, 1998; Noga, 2010; Udomkusonsri and Noga, 2005). Fish eggs are also at risk of infection from oomycetes. By initially colonising dead eggs, water moulds can spread to healthy eggs, which they could not otherwise colonise, and can cause extensive egg mortality (Eissa et al., 2013; Thoen et al., 2011).

Disease management

Transboundary spreading and zoonotic potential

Within the ornamental fish industry, live animals are transported on a global scale in substantial quantities and whenever live animals are transported from one location to another there is opportunity for co-transport of pathogens (Ariel, 2005). Therefore, a key aspect of disease management is risk consideration for the spread of pathogenic organisms. Additionally, while ornamental fishes are destined to spend their lives in captivity, escapes or intentional releases can pass on pathogens to naïve natural populations through a process known as transboundary spreading (Chan et al., 2019; Munson et al., 2024). The trade in ornamental fishes has been implicated in spreading viruses, bacteria, and parasites to native fishes outside their natural ranges (Dikkeboom et al., 2004; Taylor et al., 2013; Whittington and Chong, 2007). This is typically an issue with cold water ornamental species (e.g. koi and goldfish), as many countries importing ornamental fishes are located in temperate regions where tropical species are less likely to survive on release. However, some typically tropical species have been found in temperate regions (Munson et al., 2024), and rising global water temperatures may increasingly exasperate the problem.

Humans are also susceptible to transboundary spreading via fish-human zoonoses. In 2012, a systematic review of ornamental fish-human zoonoses highlighted *Mycobacterium marinum* as the greatest cause for concern, with at least 32 recorded case reports (single occurrence of human illness) and 16 case series (two or more occurrences of human illness) of human *M. marinum* infection linked to ornamental fish exposure, including potential links to three deaths in immunocompromised individuals (Weir et al., 2012). Other cases have been reported since (Bouceiro-Mendes et al., 2019; Huang et al., 2012), and a more recent review found strong molecular and epidemiological evidence for zoonotic *Mycobacterium* transmission (Gauthier, 2015). Gauthier (2015) also highlighted three other zoonotic pathogens (*Clostridium botulinum*, *Streptococcus iniae*, and *Vibrio vulnificus*). However, these were more related to consumption or handling of food fishes, with little relevance to fish kept as pets. The true extent of human-fish zoonoses is likely underestimated due to limited awareness and monitoring/surveillance (Haenen et al., 2020a; Ziarati et al., 2022). For example, infection by *Mycobacteria marinum*, is not notifiable in most countries (Ahmed et al., 2020; Haenen et al., 2020a). Due to the relative frequency of exposure, professionals within the ornamental industry are most at risk from zoonotic diseases, but there can also be a risk to the home aquarist (Haenen et al., 2020a).

Addressing the zoonotic issues described above will require a ‘One Health’ approach (CDC, 2020) which has been adopted successfully in combating a number of zoonoses from terrestrial animals such as zika, rabies, and hendra virus (reviewed in Horefti, 2023). A framework has already been proposed for a ‘One Health’ approach to sustainable food-producing aquaculture (Stentiford et al., 2020) and while animals destined for human consumption naturally pose a greater zoonosis risk, consideration of a similar framework for ornamental fishes is warranted. An additional complexity associated with the risk of zoonotic diseases, is the release of antibiotics and antimicrobial resistance genes to the environment where they can pass to human pathogens (Santos and Ramos, 2018). Effluent from an ornamental fish market in China identified numerous antibiotics, antimicrobial resistance genes, and potential opportunistic human pathogens (Liu et al., 2021) and effluent from ornamental fish farms in Sri Lanka contained multidrug-resistant *Aeromonas* spp. (Dhanapala et al., 2021). Recommendations already exist which could be implemented into a ‘One Health’ approach including monitoring ornamental fish stocks and consignments for zoonotic and AMR pathogens, raising awareness of zoonotic diseases, promoting proper hygiene and biosecurity practices, monitoring and regulating antibiotic use (Dhanapala et al., 2021; Haenen et al., 2020b, 2020a; Kušar et al., 2017; Phillips Savage et al., 2022; Weir et al., 2012; Ziarati et al., 2022).

Disease Treatments

The prevalence and severity of diseases within ornamental fishes, along with their zoonotic potential, highlights the need for effective antimicrobial treatments. ‘Antimicrobial’ is an umbrella term which describes any chemical (synthetic or naturally derived) that kills or inhibits growth of microorganisms. As such, this spans a wide range of chemicals including disinfectants, antiseptics, antibiotics, antifungals, antivirals, antiparasitics and antiprotozoals. In the literature, the terms ‘antimicrobial’ and ‘antimicrobial resistance’ are usually used synonymously with ‘antibiotic’ and ‘antibiotic resistance’ respectively. Throughout this review, where possible the class of chemical discussed (e.g. antibiotic, antifungals, disinfectants, antiseptics, etc.) will be used, accepting that some compounds may have more than one specific action. When referring to a combination of these compounds, or where it is not clearly stated in previous literature, the general term ‘medications’ will be used.

Ornamental fish may be administered medications in different ways. Bath treatments are where the fish is added to water containing relatively low concentrations of the medication, typically for a period of 2-60 minutes (Loh, 2015). For dip treatments fish are exposed to the chemical in a contained volume of water for shorter durations with typically higher concentrations of medications (Mashima and Lewbart, 2000). Prolonged immersion can also be used, where a very low concentration of medication is introduced to the tank water for a longer exposure duration, typically many days (Loh, 2015). While injections are an option for treating fishes, particularly in the case of vaccination, they are usually impractical for small ornamental fishes particularly in commercial settings. This is due to their small body sizes, frequency and size of consignments, individual fish value, cost, and labour intensity involved (Yanong, 2003). The final major route of administration is through medicated feeds. Here, fish food is coated with medications before feeding or they are added to the feed during production. This method of administration requires less medication than dip or bath treatments, but relies on the fish having an appetite, which can be non-existent in severe cases of infection (Yanong, 2003).

There are few data on the comparative efficacy of different routes of administration, most of which come from an aquaculture setting. When silver perch (*Bidyanus bidyanus*) were treated with antiparasitics to control monogean gill parasites, oral treatments were comparable to bath treatments for one medication but performed worse for another (Forwood et al., 2013). Some fish medications can reduce palatability leading to feed and hence medication being rejected, hampering effectiveness (Forwood et al., 2013; Marking et al., 1988). In red pacu (*Colossoma brachypomum*) and koi carp (*Cyprinus carpio koi*) oral, intramuscular injections (and intraperitoneal in koi), and bath treatments of the antibiotic enrofloxacin all provided therapeutic blood concentrations (Lewbart et al., 1997; Udomkusonsri et al., 2007). However, in the oral treatments gastric lavages were used rather than medicated feed which eliminates the limitation of palatability but increases labour intensity significantly. In Nile tilapia (*Oreochromis niloticus*) the antibiotic oxytetracycline was more effective against an *Aeromonas hydrophila* infection when provided as medicated feed rather than as a bath treatment (Julinta et al., 2017). Similarly, in common carp (*C. carpio*), the antibiotic florfenicol was more readily absorbed when provided as a medicated feed rather than a bath treatment (Jangaran Nejad et al., 2017).

Ornamental fish supply chains often involve many parties in both the exporting and importing country. Most freshwater ornamentals originate from fish farms in Asia Pacific countries such as Singapore, Indonesia, and the Philippines (Jones et al., 2021). In these farms, fishes may be treated with medications prophylactically (preventatively; in absence of disease), therapeutically (to cure active disease), and possibly in some cases for growth promotion, despite the latter having no scientific basis and some evidence it could decrease gut health (Trushenski et al., 2018; Weir et al., 2012; Zhou et al., 2018). Obtaining data on treatments at this stage is difficult, as ornamental fish farms are typically small family operated businesses and are reluctant to share husbandry practices established through many years of trial and error (Chapman, 2000). As fishes are traded between different parties, they could experience different medications at each stage in the supply chain, particularly during long transports between importing and exporting countries where medications are often added prophylactically to increase survival (Cole et al., 1999; Dobiasova et al., 2014). Fishes may even be treated with chemicals banned in the destination country, as different countries have different rules and regulations on fish medication use (Haenen et al., 2020). For example, in the UK, all antibiotics used to treat animals fall into class POM-V (prescription only medicine – Veterinarian) and must be prescribed by a veterinarian (Veterinary Medicines Directorate, 2016). However, in the US many antibiotics used to treat fish are available to purchase online or over the counter (Zhang et al., 2020). In addition, in countries where antibiotics are available, there are generally strict regulations in place for antibiotic use in finfish aquaculture destined for human consumption, but not for ornamental fish aquaculture. Regulations do not typically exist for ornamental fishes, or are unenforced if in place (Weir et al., 2012). For example, the US Food and Drug Administration (FDA) regards ornamental fishes as a low regulatory priority (Yanong, 2003). Once the fish have reached the end user in the supply chain, the home aquarist, the choice of treatments will likely be very different to those routinely used in commercial settings, particularly in exporting countries. It is worth noting, fish are typically given quarantine periods before being added to aquaria both in a commercial setting and when kept by the more dedicated hobbyist. For example, public aquaria generally quarantine new individuals for a minimum of 30 days before introducing to established aquaria (Hadfield and Clayton, 2011). During this time, typically at least two weeks, fish can undergo health monitoring to look for early warning signs of disease in addition to the application of a variety of prophylactic fish medications. However, while health monitoring as a preventative tool has been used successfully for tropical ornamentals within research facilities (Collymore et al., 2016; Mocho, 2016), it is not well developed for the home aquarist.

Treatments within commercial settings

The scarcity of data on antibiotic use within the ornamental trade was recognised by Weir and colleagues (2012). They sought to rectify this by surveying aquaculture-allied professionals with expertise in ornamentals and antibiotic use. The surveys covered all aspects of antibiotic use in the ornamental sector including purpose, production phase, and class of antibiotic used. Most participants stated antibiotics were commonly used, mostly therapeutically rather than prophylactically. Quinolones, tetracyclines, and nitrofurans were among the most used classes of antibiotic, although occasional to frequent use was reported for all classes by at least some respondents. However, the majority of survey participants were from North America (92 out of 113; 81.4%). This becomes problematic for interpretation considering that Asia and Europe contribute ~57% and ~28% of global ornamental exports respectively (Dey, 2016). Therefore, the surveys likely do not capture the true use of antibiotics within the trade.

Another way to obtain data on fish medication use within the trade could be the screening of carriage water for medication residues. When 50 consignments of ornamental fishes imported into the Netherlands from 13 countries were screened for medication residues, 49 of them contained one or more antibiotics at detectable levels, including antibiotics which are banned in the EU such as chloramphenicol and nitrofurans (36 and 68% of consignments respecitvely; Haenen et al., 2020). By examining carriage water samples, data can be collected on fish medication use from exporting countries independently of reporting bias. However, if medications are used early in the production cycle prior to export then there is a possibility they would not be represented. Additionally, different classes of antibiotics vary in their persistence within aquatic environments (Kümmerer, 2009). Therefore, there is the potential for less stable compounds to be underrepresented. Another way to estimate use of fish medications is through sales data, however, these data are not readily available on a global scale. It is important to monitor antibiotic use within the trade as inappropriate use can result in antimicrobial resistance (AMR).

Antimicrobial resistance (AMR) within ornamental fish pathogens

One of the main problems associated with the disease treatments used during the commercial phases of the ornamental trade is the emergence of antimicrobial resistance (AMR), a concept typically associated with antibiotic use (Narendrakumar et al., 2023). AMR develops rapidly in bacterial populations (Baym et al., 2016) and the last systematic review on the extent of

AMR within the ornamental industry was published more than a decade ago (Weir et al., 2012). Therefore, an update on the subject is prudent. While recent reviews have considered AMR in aquaculture (Preena et al., 2020b), the focus is on food fishes with little emphasis given to fish kept as companion animals. Some bacteria have intrinsic resistance to different classes of antibiotics. For example, all Gram-negative bacteria possess intrinsic resistance to glycopeptides (e.g. vancomycin) and lipopeptides (e.g. daptomycin) due to reduced permeability of their outer membrane (Reygaert, 2018). Other mechanisms can confer intrinsic resistance such as the chromosomally encoded efflux pumps in *Pseudomonas aeruginosa*. These pumps confer resistance to a wide range of antibiotics (e.g. tetracycline, chloramphenicol, and norfloxacin) by actively transporting them out of the cell (Li et al., 1994). This intrinsic resistance emphasises the need to establish which bacterial pathogen is being treated and target with suitable antibiotics rather than treating prophylactically. When antibiotics are used inappropriately acquired resistance can also occur.

Acquired resistance can arise through natural mutations resulting in AMR genes which confer resistance by four main routes: reducing antibiotic uptake (Quinn et al., 1986), modification of antibiotic target (Jaktaji and Mohiti, 2010), inactivating the antibiotic compound (Murray and Shaw, 1997), or its active expulsion via efflux pumps (Li and Nikaido, 2009). AMR genes can exist in variable abundances within bacterial populations but can become more common when inappropriate antibiotic use acts as a selection pressure causing a genetic bottleneck increasing their relative abundance in the new population (Mahrt et al., 2021). Additionally, AMR genes are often present on plasmids, which can be transferred between bacteria through any method of horizontal gene transfer (HGT) such as transformation, transposition, and conjugation (Reygaert, 2018; Strahilevitz et al., 2009). Acquiring AMR genes is not always a benefit fitness for the organism, for example the genes *Staphylococcus aureus* acquires to become resistant to methicillin and other β-lactam antibiotics also significantly decreases its growth rate (Rolinson, 1998). Regardless, the acquisition of AMR genes in pathogens make the diseases they cause considerably harder to treat.

The rise in AMR has implications for treating ornamental fishes, and also for human health as reservoirs of AMR genes can be passed by HGT to human pathogens (Lupo et al., 2012; Preena et al., 2020b). This becomes particularly problematic as many antibiotics useful for treating fish diseases are also used for treating human diseases (Cabello, 2006). To test for the extent of AMR in the ornamental trade, pathogens have been obtained from ornamental fishes by culturing swabs taken from the skills and gills, or the homogenized internal organs, or even filtered from the water. Once cultured, bacteria are exposed to antibiotics either using minimum inhibitory concentration (MIC) or disk diffusion assays to determine if the pathogens are resistant or susceptible to the tested concentrations of antibiotics (CLSI, 2022). The prevalence of AMR within the ornamental trade is wide ranging and within most classes of antibiotic (Weir et al., 2012). Nevertheless, high resistance to penicillin, tetracycline, sulphonamide, and quinolone classes were commonly reported.

The PRISMA method was used to undertake a systematic review to update our understanding of the prevalence AMR within the ornamental industry with a focus on fish held as companion animals (Page et al., 2021). In May 2022 and repeated in October 2023, the following search term: 'Antimicrobial resistan* AND Ornamental fish*' was searched on Web of Science and Scopus retrieving articles published from 2010 onwards. The search returned 61 and 46 results from Web of Science and Scopus respectively. After duplicates were removed 71 unique articles remained which underwent initial screening of relevance by reading the title and abstract, removing irrelevant articles (removed n=18). The full texts of the remaining 53 articles were then assessed against the following inclusion criteria: papers presenting data from < 20 isolates were not included for brevity (removed n = 11), must be original research not a review paper (removed n = 6), data must be provided on pathogens isolated from ornamental fishes or their water, data on pathogens from food fish species or a mixture of the two where pathogens from ornamentals could not be distinguished were not included (removed n = 10), article must be in English (removed n = 1), and must provide data on the percent of isolates resistant to the antibiotics (removed n = 5). An additional study was removed as it was not accessible. The remaining 19 studies were accepted, and the following data were extracted: bacterial species studied (species and number of isolates), geographical origin of samples (country and type of facility), biological origin of samples (fish species, organ sampled, water samples), antibiotics tested and percent of isolates resistant, and multiple antibiotic resistance (MAR) index (number of antibiotics an isolate is resistant to divided by the total number of antibiotics tested). Where data were only presented graphically, numerical values were obtained using GetData Graph Digitizer ver. 2.26.0.20.

In the analysis of the results from this systematic approach and similarly to the findings of Weir, there was considerable variation in resistance to most of the antibiotics tested (Table 2). Generally, bacterial isolates showed relatively low resistance (mean % of isolates resistant: 2.8 – 22.9) to the following antibiotic classes; 3rd generation cephalosporins (e.g. cefotaxime, ceftazidime, and ceftriaxone), carbapenems (e.g. meropenem, doripenem, imipenem), and aminoglycosides (e.g. tobramycin, amikacin, and gentamycin). High resistance was generally shown (mean % of isolates resistant: 21.2 – 87%) to penicillins (e.g. ampicillin, amoxicillin) and tetracyclines (e.g. tetracycline, oxytetracycline), indicating heavy use of these antibiotics within ornamental fish culture.

The results of this review are generally in accordance with Weir et al. (2012) as pencillins and tetracyclines were largely ineffective in their findings. However, some classes of antibiotics performed better in recent years than in the previous findings. Weir found high resistance to cephems (the subclass of antibiotics that includes the cephalosporins and cephamycins) in some cases. In the present review most cephems showed relatively low resistances aside from the 1st generation cephalosporins. As Weir does not distinguish between the generations of cephalosporins it is difficult to make direct comparisons. Conversely, some classes of drugs performed worse. While carbapenems generally showed low resistance, some studies found levels of resistance higher than those found by Weir, possibly indicating an increase in the use of these antibiotics.

Less than half of the studies reported the MAR index of the isolates they were testing (Table 2). A MAR index > 0.2 indicates the isolate originates from an environment with a high antibiotic presence (Davis and Brown, 2016). Of the studies which did report MAR ($n = 7$), all reported isolates with MAR > 0.2. Additionally, in four of the studies, all isolates tested exceeded the 0.2 threshold. Whilst this is a relatively small sample size, it does hint at the prevalence of unsuitable antibiotic treatments within the ornamental fish trade.

In vitro assays such as MIC and disk diffusion are considered the gold standard to determine an antibiotic’s effectiveness against pathogens (Khan et al., 2019). However, effectiveness shown in these tests is not guaranteed to translate to successful treatment of diseases *in vivo*. Comparatively few *in vivo* efficacy trials have been undertaken for antibiotics used with ornamental fishes, relative to *in vitro* trials and there is a clear paucity in data on *in vivo* efficacy of many antibiotics used. Zebrafish with skin scrapes experimentally infected with *Aeromonas hydrophila* showed significantly higher survival when treated with the antibiotic gentamicin in ultrapure water compared to gentamicin in slightly saline water (0.9% NaCl) and the untreated infected fish (Gao et al., 2021). Clearly more *in vivo* treatment trials are needed on a range of fish species and pathogens to guarantee antibiotic effectiveness, allow targeted commercial treatments based on scientific evidence, and reduce the risk of AMR. It is worth noting that antibiotics are not the only class of treatment where resistance can be developed. For example, bacteria can also become resistant to disinfectants (Tong et al., 2021). Equally other taxa of pathogen can become resistant to their respective treatments such as anthelmintic resistance in monogeneans (Waller and Buchmann, 2001), or antifungal resistance in fungal pathogens (Lee et al., 2023). However, given the scale of antibiotic use, the prevalence of bacterial disease within the ornamental fish industry, and the threat resistance poses to human health, we have focused on antibiotic resistance in this review.

Treatments within home aquaria

The unsuitability of antibiotic treatments for home aquaria, coupled with growing concern in the rise of AMR presents the need for alternative treatments. There are a range of alternative treatments available to the home aquarist, some of which may also be used at a commercial level. Most of these treatments contain therapeutic dyes or plant-derived essential oils as their active ingredients. In a recent survey of over 350 participants, it was found that hobbyists purchase proportionally more natural products compared to retailers but also that there is a tendency by hobbyists not to adhere to manufacturer instructions for exact dosing protocols (Arapi and Cable, unpublished data). In addition to this, in a home aquaria setting treatments may be administered without proper diagnosis leading to treatment failure and implications for animal welfare. To determine the quantity of scientific information available on these alternative treatments, a systematic search of ornamental fish treatments from the BSAVA (2020) Small Animal Formulary Part B: Exotic Pets Appendix III; Proprietary fish medicine vendors, was carried out using Web of Science and Scopus in October 2022, October 2023 and June 2024. The search term was mainly the name of the product, however, where products had generic names which generated excessive hits the brand name was specified prior to the product using the Boolean operators “”. Table 3 summarises the number of articles returned and whether or not the article related to the treatment of ornamental fishes and/or their pathogens *in-vitro*. It is immediately clear that there is a substantial lack of knowledge on the efficacy of most of these treatments even though most are marketed on a global scale. Given the lack of knowledge on specific treatments, the following sections are focused around the main active ingredients in order to highlight gaps in our knowledge and stimulate further research.

Plant-derived essential oils

A number of plant-derived essential oils have been marketed to treat diseases within home aquaria. One such oil is cajuput oil, a mixture of essential oils derived from the cajuput tree (*Melaleuca cajuputi*). Cajuput oil mostly consists of terpenes, such as 1,8-cineole and limonene (Schelkle et al., 2015b) although the exact composition of essential oils can vary seasonally and regionally and can exhibit distinct chemotypes (Homer et al., 2000; Idrus et al., 2020). MELAFIX (API) is a product marketed globally to control home aquarium bacterial diseases where the active ingredient is 1% cajuput oil. The minimum inhibitory concentration (MIC) and minimum bactericidal concentration (MBC) of MELAFIX on an assortment of known fish pathogens (*Aeromonas salmonicida* subsp. *salmonicida*, *Listonella anguillarum*, *Pasteurella piscicida*, *Photobacterium damselae* subsp. *piscicida*, and *Streptococcus iniae*) was determined using the microbroth dilution technique (Shivappa et al., 2015). MELAFIX was unsuccessful in inhibiting the growth of pathogens and all but one isolate had MBCs and MICs greater than the maximum concentration. The concentration tested (up to 83.2 µl ml^{-1}) was two orders of magnitude greater than the recommended daily dose of MELAFIX (i.e. dose for 7 days at 5 ml per 10 US gallon = 0.13 µl/ml). However, these *in vitro* tests were done in Meuller-Hinton broth, which is likely to be more nutrient rich than home aquarium water and it is possible that MELAFIX would be more successful in inhibiting bacterial growth at more representative nutrient concentrations. Additionally, testing was conducted at 37°C which would increase the volatility and hence reduce efficacy of the active components of this botanical oil. Temperature also has the potential to influence MIC testing directly (Smith et al., 2018). Furthermore, *in vitro* MIC assays performed using emulsified cajeput oil against the pathogens *A. hydrophilia,* and *F. columnare*, significantly reduced optical density when compared to a no-treatment control (O'Brine, et al., submitted for publication 2023), suggesting some anti-bacterial activity.

While it is unclear the extent of the anti-bacterial activity of MELAFIX, there is speculation that beneficial effects of the product may be due to immunostimulant rather than antimicrobial properties as there is evidence within the literature that essential oils can have antioxidant potential. In silver catfish (*Rhamdia quelen*) bathing in 50 µl l^{-1} of nano-encapsulated tea tree oil (derived from the congener *Melaleuca alternifolia*) for 1 h daily, reduced hepatic oxidative damage caused by experimental infection with *Pseudomonas aeruginosa* (Souza et al., 2017). Similarly, free tea tree oil protected *R. quelen* from hepatic oxidative damage caused by *Aeromonas hydrophilia* infection (Baldissera et al., 2017), where hepatic oxidative damage may be a key factor in the progression of bacterial disease (Baldissera et al., 2018; Biazus et al., 2017; Castro et al., 2017).

The one *in vitro* efficacy study mentioned above also established the effect of MELAFIX on marine and freshwater general fish health *in vivo* (Shivappa et al., 2015). Aquaria (75 l, n =3) were stocked with 10 clownfish (marine) or goldfish (freshwater) and underwent daily dosing with MELAFIX for 2 weeks with water changes performed on day 7 and daily for 2 weeks post treatment. No distress behaviours or histopathological changes (compared to a control tank without MELAFIX) due to MELAFIX treatment were noted. A study evaluating the antiparasitic properties of cajuput oil (at comparable concentrations to MELAFIX) against *Gyrodactylus turnbulli* infection in guppies (*P. reticulata*) also observed no signs of behavioural distress during the first hour of treatment (Schelkle et al., 2015a) where fish were treated in isolation. While these studies suggest no negative effects of MELAFIX, behavioural observations following MELAFIX treatment have been limited to temporary distress behaviours.

West Indian bay tree (*Pimenta racemose*) oil is another essential oil mixture promoted as an antimicrobial treatment for ornamental fish pathogens. PIMAFIX (API) is a product marketed globally to combat fungal infections in home aquaria where its active ingredient is 1% *Pimenta racemose* essential oils. The oils consist mostly of eugenol, chavicol (phenols), and the monoterpene myrcene (McHale et al., 1977; Schelkle et al., 2015b). No published studies were identified on the efficacy of PIMAFIX for treating fungal infections (or fungal-like oomycete infections) in fishes. However, preliminary data supporting a significant reduction in fungal hyphae growth on ricefish eggs (*Oryzias woworae*) using PIMAFIX as a stand-alone treatment compared to a methylene blue control has been established (Snellgrove, D and O'Brine, T, unpublished data). West Indian bay oil has antifungal properties when its fumes (28×10^{-3} mg ml^{-1} air) were used to inhibit growth of two phytopathogenic fungi *Phytophthora cactorum* (69.1 ± 11.6% inhibition) and *Cryponectria parasitica* (75.2 ± 2.4% inhibition) (Kim et al., 2008). Many plant-based essential oils, particularly thyme, *Thymus vulgaris*, and oregano, *Origanum vulgare*, have strong antifungal properties against *Saprolegnia parasitica*, perhaps the most common fungal-like pathogen of fishes (Gormez and Diler, 2014; Nardoni et al., 2019; Tampieri et al., 2003). However, these essential oils contain different volatile constituents to West Indian bay oil (Nardoni et al., 2019; Schelkle et al., 2015b). Therefore, it is unclear if West Indian bay oil would be as effective and warrants further investigation. Regardless, PIMAFIX, in combination with MELAFIX was found to be 95% effective as an antiparasitic agent against *Gyrodactylus turnbulli* infection in guppies (Schelkle et al., 2015b).

Another plant-derived treatment used within fish-keeping communities is garlic (*Allium sativum*). Allicin, the major active compound of garlic has broad antimicrobial capabilities with demonstrated antibacterial, antiparasitic, antifungal, and antiviral activity (reviewed in: Ankri and Mirelman, 1999). While there are garlic-based fish keeping products on the market in the UK, most are marketed as dietary supplements or appetite stimulants, whilst occasionally listing disease prevention as a secondary function. Despite this, ‘home-made’ garlic treatments are often used and can be prepared in various ways including dried (Schelkle et al., 2013), crushed (Fridman et al., 2014), and minced/pureed (Sasmal et al., 2005; Schelkle et al., 2013). However, the most scientific attention has been given to garlic extracts created with a variety of solvents including water, methanol, and ethanol, with the latter extracting the greatest variety of active chemical compounds (Ahmadniaye Motlagh et al., 2020; Fridman et al., 2014; Gholipour-Kanani et al., 2012; Saha and Bandyopadhyay, 2017; Sahandi et al., 2023; Sasmal et al., 2005).

Fluke infections (*G. turnbulli*) were controlled in guppy (*P. reticulata*) by using Chinese freeze dried garlic powder (0.03 mg ml^{-1}), freeze dried garlic flakes (1 mg ml^{-1}) and allyl disulphide (an allicin derivative, 0.5 mg ml^{-1}) as successfully as a levamisole control group (Schelkle et al., 2013). This is in agreement with Fridman et al. (2014) who found 1 hour baths of 7.5 and 12.5 ml l^{-1} aqueous garlic extract significantly reduced *G. turnbuli* prevalence and severity in *P. reticulata*. Additionally, when their food was supplemented with 10-20% dried garlic powder for 14 days, intensity and prevalence of *G. turnbulli* and *Dactylogyrus* sp. (another fluke) infection was significantly reduced (Fridman et al., 2014). Ethanolic extract of garlic was found to treat goldfish (*C. auratus*) infected with tichonodinid ciliates (protozoan parasites) in a dose dependent manner with 15 mg l^{-1} completely curing the infection after 8 days of treatment (Saha and Bandyopadhyay, 2017). White spot disease in sailfin molly (*Poecilia latipinna*) and guppy (*P. reticulata*) was cured after 5 and 4 days of bath exposure to 0.1 g l^{-1} garlic extract respectively (Gholipour-Kanani et al., 2012).

The effectiveness of garlic is not limited to treating parasites, when tested *in-vitro*, crude aqueous garlic extract inhibited 80% of the growth of *Aeromonas* sp. and *Psuedomonas* sp. strains at concentrations of 0.40-0.41% and 0.99-1.43% respectively (Sasmal et al., 2005). Supplementing fish diets with garlic seems to confer protective benefits. When goldfish (*C.*

auratus) were a fed garlic paste-supplemented diet at a rate of 1 g per 100 g feed, they did not exhibit fin/tail rot up to 30 days post *Pseudomonas fluorescens* challenge whereas 20% of fish fed the control diet did (Sasmal et al., 2005). Additionally, when aqueous garlic extract was incorporated into the diet of female guppy juveniles (*P. reticulata*) for 80 days at levels of 0.1 - 0.2 ml kg^{-1} diet, non-specific skin mucus immune parameters were elevated, with optimum levels found at 0.15 ml kg^{-1} (Ahmadniaye Motlagh et al., 2020).

Despite this promise there is some concern over the effects of garlic treatments on fish health. When white spot infected guppy (*P. reticulata*) were given long term (14 day) baths of a therapeutic dose of garlic extract (0.1 g l^{-1}) histopathological changes were seen in key organs. A multitude of changes occurred in the gill tissue including epithelial hyperplasia, interstitial edema resulting in severe epithelial lifting in secondary lamellae, degeneration of secondary lamellae, reduced length of primary lamellae, severe lamellar fusion, increased space between filaments, vasodilatation, and blood congestion. Whereas in the liver, nuclear pyknosis, cytoplasm and vacuolar degeneration and hepatic necrosis were seen (Sahandi et al., 2023). Furthermore, fluke infected (*G. turnbulli* and *Dactylogyrus* sp.) guppies (*P. reticulata*) fed 10-20% garlic powder-supplemented feed showed elevated muscular dystrophy relative to untreated infected fish when histologically examined (Fridman et al., 2014). Garlic treatments have been shown to cause slight fin damage in a dose-dependent manner in fluke infected guppies, although this was not quantified. However, the authors noted the damage healed relatively quickly (within weeks of the treatment ceasing; Schelkle et al., 2013). It is unclear whether the gill or liver tissue changes in the previously mentioned studies reverted as longer-term monitoring was not in place and hence should be investigated.

Care should be taken when dosing with garlic-based treatments. The LC50 (the concentration which killed 50% of the treated animal) of ethanolic extract of garlic in goldfish was found to be 28.67 mg l^{-1} in 4 day bioassays (Saha and Bandyopadhyay, 2017). Mortality was seen from concentrations of 20 mg l^{-1} upwards, coupled with erratic swimming and irregular opercular movements which is close to the apparent effective dose of this extract at 15 mg l^{-1}. In healthy guppies, aqueous garlic extract (15 ml l^{-1}) started to cause mortality after 1 h of exposure with 100% mortality shown by 6 h of exposure (Fridman et al., 2014). Again, this was close to the effective dose of 12.5 ml l^{-1} for 1 h. The possibility of overdosing when treating with garlic perhaps limits its practicality as a treatment for the inexperienced home aquarist.

Salt (Sodium Chloride)

There is evidence that salt may be an effective treatment against a range of fish parasitic diseases including *Ichthyophthirius multifiliis* (white spot disease). *In vitro* studies of short exposures (24 h) to varying levels of salt (2.5-20 g l^{-1}) show the infective theronts of *I. multifiliis* are susceptible to salt concentrations greater than 2.5 g l^{-1} (50% mortality) with 5-10 g l^{-1} being most effective resulting in ≥ 95% mortality (Shinn et al., 2006). Feeding stage trophonts are less susceptible and can survive 10 h of exposure to 15 g l^{-1} with 0% mortality, but not 10 h at 20 g l^{-1} (Lahnsteiner and Weismann, 2007). Salt baths of variable concentrations and lengths have been tested *in vivo* in a variety of food fish species such as catfish and trout with varying success. Generally, baths of 5 g l^{-1} or more for extended periods > 7 days are effective in treating white spot in these species (reviewed in Picón-Camacho et al., 2012). However, there are comparatively fewer studies in ornamental fishes.

When an outbreak of white spot occurred in an aquarium retailer's stock of black mollies, *Poecilia sphenops,* a sea salt bath (10 g l^{-1}) reduced parasite burden to zero in 3 days at 27 °C without fish mortality (Maceda-Veiga and Cable, 2014). Similarly, when fingerlings of iridescent shark catfish (*Pangasianodon hypophthalmus*) were treated for white spot with 1% salt and elevated temperatures (24 to 30 °C) the infection cleared up after 15 days (Mamun et al., 2020), although mortality rates were high. It is possible the infection was too advanced as salt baths are reportedly more effective in the early stages of white spot (Maceda-Veiga and Cable, 2014); when the same treatment was applied to angelfish, *Pterophyllum scalare,* and gold gourami, *Trichopodus trichopterus,* with a lighter parasite burden, survival was improved (Mamun et al., 2021). The use of elevated temperatures was likely important as an increased temperature accelerates the *I. multifilis* lifecycle and hence emergence of the salt-susceptible theront stage (Dickerson, 2011; Lahnsteiner and Weismann, 2007).

Another parasitic disease of ornamental fishes that seems to be effectively controlled with salt is external infection with flukes. The *in vitro* and *in vivo* survival of the guppy-parasitising fluke congeners *Gyrodactylus turnbulli* and *G. bullatarudis* were tested under varying salt concentrations (Schelkle et al., 2011). Survival of both fluke species decreased with increasing salt concentrations, surviving < 1 h at 33 g l^{-1}. However, when tested *in vivo* on guppies, *Poecilia reticulata,* the two parasites differed in their tolerances. To establish the preventative effects of salt, the guppies were gradually habituated to 3 or 7 g l^{-1} salinity over 7 days and then experimentally infected by close proximity to a donor fish while anesthetised. *G. turnbulli* failed to establish on 100% of guppies acclimated to 7 g l^{-1} whereas *G. bullatarudis* successfully established on ~72% guppies at the same salinity. Furthermore, a similar pattern emerged when using higher concentration salt baths as a treatment for guppies already infected with *Gyrodactylus*. When exposed to 15 min baths (five baths for juveniles) of 15 and 25 g l^{-1}, survival of both parasites decreased with increasing salinity. However, *G. bullatarudis* was less affected by the salt baths with 73.3% efficacy at 25 g l^{-1} compared to 100% efficacy in *G. turnbulli*. These treatments should be used with caution, particularly in juveniles. Routine monitoring post-experiment showed increased mortalities in the juvenile fish exposed to the shorter salt baths. This mortality was not fully quantified and thus remains anecdotal in nature. More studies should be done to investigate the efficacy of salt baths for treating ornamental fishes with parasites.

The effectiveness of salt in treating parasitic diseases has led to speculation on its potential to treat external bacterial infections, particularly those caused by species sensitive to salt, such as *Flavobacterium columnare* (Columnaris disease). *In vitro* data suggest short baths (15 mins) of 4% NaCl were 95-100% effective in killing *F. columnare* strains (Suomalainen et al., 2005). However, *in vivo* in experimentally infected rainbow trout, *Oncorhynchus mykiss*, all fish succumbed to *F. columnare* infection by 6 days post infection despite being treated with 4% NaCl baths on days 1 (15 min bath), 3, and 5 (both 5 min baths; Suomalainen et al., 2005). While the salt baths were ineffective at reducing fish mortality, a delay in mortality caused by columnaris disease was seen, potentially through salt killing bacteria shed from the fish epidermis, reducing the transmission rate to conspecifics.

Despite little evidence to suggest salt dips can be used therapeutically for bacterial diseases, prolonged exposure to salt may be effective as a preventative measure. When four species of fish, including goldfish (*C. auratus*) were acclimated to higher salinities for a period of 4-10 weeks, mortality was significantly reduced following experimental *F. columnare* infection (Altinok and Grizzle, 2001). In untreated goldfish, mortality was 66.5% at 5 days post exposure to *F. columnare*, compared to 40.8% in fish acclimated to 1 ‰, and 0 % in fish acclimated to 3 and 9 ‰. These results could be explained by reduced adherence and biofilm formation capabilities of *F. columnare* at salinities ≥ 3‰ (Altinok and Grizzle, 2001; My et al., 2020). Adherence and biofilm formation are both important factors in the initial colonisation of fish tissue and thus disrupting them may have been a key factor in reducing mortalities (Declercq et al., 2021).

While 3-9 ‰ salinity seems to be an effective preventative measure for columnaris disease in goldfish, the long-term effects of salinity on the health of freshwater ornamental fishes are unclear. Goldfish kept for 21 days at 8-10‰ had significantly reduced growth, whereas koi kept at 12‰ for 4 months did not (Luz et al., 2008; Sharma et al., 2017). Goldfish kept at 5‰ for 21 days showed decreased blood pH, blood ionic imbalance and alteration of gill structure with increased mucus secretion, swollen blood vessels and lesions (Da Silva et al., 2021). There are clear gaps in our understanding of the effects of long-term salt exposure on freshwater ornamental fish health. Additionally, salt treatments are not suitable for aquaria containing live plants as many freshwater plants are intolerant of even low levels of salt (Tootoonchi and Gettys, 2019).

Therapeutic dyes

There are a range of therapeutic dyes with antiparasitic, antifungal and antibacterial properties that have been used to treat ornamental fishes. Malachite green has a long history of use in fish treatment. It was first reported as a treatment for fungal infection of trout and as a disinfection treatment for their eggs in 1936 (Foster and Woodbury, 1936). In the 1960s it was demonstrated to be a useful antiparasitic agent, particularly against white spot (Johnson, 1961) and for the rest of the 20th century was used routinely in aquaculture as an antiparasitic, antifungal and egg disinfectant. However, in 2000 malachite green was banned in the EU for use in food fishes due to its persistence in fish tissues and evidence of toxic and carcinogenic properties (Sudova et al., 2007). Despite this, malachite green is still used in many products commonly sold to control parasitic and fungal diseases in ornamental fishes.

Malachite green is known to be highly toxic to fishes and the recommended therapeutic dose can often come close to the lethal dose, which can vary greatly between species (Intorre et al., 2007; Souza et al., 2020; Sudova et al., 2007). For example, in jewel cichlid, *Hemichromis bimaculatus,* no harmful effects were observed at 0.25 - 0.5 mg l^{-1} malachite green for 96 h, which is greater than maximum recommended prolonged dose for ornamental fishes: 0.2 mg l^{-1} (Noga, 2010; Souza et al., 2020). However, in goldfish, *Carassius auratus,* and zebrafish, *Danio rerio,* the recommended short-bath therapeutic dose (2 ppm for 0.5 h) caused 10% cumulative mortality in both species by 14 days post treatment (Intorre et al., 2007). In addition, fish treated with the therapeutic dose showed sub-lethal responses to the malachite green including reduced activity and loss of equilibrium. When the same concentration was applied over an extended period (2.5 h) the mortality was increased in goldfish (90% cumulative mortality at 14 days post treatment) but not zebrafish (Intorre et al., 2007). The effectiveness of malachite green may also vary between species. When iridescent shark catfish fingerlings, *P. hypophthalmus*, received a combination treatment of formalin (25 ppm) and malachite green (0.1 mg l^{-1}) a heavy infection of white spot was not successfully treated (Mamun et al., 2020), but the same treatment successfully resolved an infection in mollies, *Poecilia sphenops*, in 6 days without any mortality (Maceda-Veiga and Cable, 2014). Treatment of scaleless fishes with malachite green is not recommended due to its toxic effects (Mamun et al., 2020) and is likely to be a contributing factor in the difference between these two studies.

Another therapeutic dye used in the trade is methylene blue which is used as an antiparasitic for fishes and an antifungal bath treatment for eggs. It increases hatch rate in ornamental fish eggs at 3 mg l^{-1}, although this is species-specific occurring in angelfish, *Pterophyllum scalare*, but not in zebrafish, *Danio rerio* (Chambel et al., 2014). Methylene blue is considered to have a lower toxicity than malachite green (Alam et al., 2011; Bolivar et al., 2012), but is used in higher doses to achieve the same effects (2 mg l^{-1} compared to 0.1 mg l^{-1}) and can result in mortality in some species (Tieman and Goodwin, 2001). Repeated exposure to 2 mg l^{-1} reduced growth performance and some immunological markers in goldfish (Soltanian et al., 2021). However, despite this, when challenged with *Aeromonas hydrophilia*, treated goldfish had better survival than untreated challenged goldfish. The use of methylene blue (1 ppm) in combination with 2% salt as a bath treatment was partially successful at resolving a heavy white spot infection in iridescent shark catfish, *P. hypophthalmus* (Mamun et al., 2020), where the salt possibly contributed negatively to treatment performance as treated fish showed extensive epithelial damage and had sloughed off epidermis (Mamun et al., 2020).

Acriflavine is another dye used for the control of parasitic infections and egg disinfection in ornamental fishes (Plakas et al., 1999), although there is little scientific evidence for its effectiveness. It is not suitable for use in ornamental fish larvae where it causes high mortalities (up to 100% in zebrafish larvae) using lower than recommended therapeutic doses (Meinelt et al., 2002; Plakas et al., 1999). Furthermore, toxicity is increased in harder water which makes it unsuitable for treatment of fishes which thrive in harder waters such as East African lake cichlids (Meinelt et al., 2002; Santos et al., 2023).

Other common active ingredients

Lice-Solve (Vet Ark) is a treatment marketed at combating ectoparasitic crustaceans where the active ingredient is emamectin benzoate. While no studies have been performed on the product's efficacy against crustaceans, one study has looked at its potential as an anthelmintic treating the gastrointestinal nematode *Pseudocapillaria tomentosa* in zebrafish (Kent et al., 2019). Lice-Solve was tested at 10 and 3 x the manufacturers recommended dose in four 24 h bath treatments. Both concentrations proved 100% effective although the weaker dose was tested on populations with less severe infections (80 vs 30% prevalence). It is unclear if the lower dose would have been as effective with greater parasite prevalence. The safety of the product was also assessed in concentrations of 10 and 5 x the manufacturers dose. No mortality was seen. However, behaviours indicative of stress (rapid respiration, staying near tank bottom) were seen in the higher concentration although fish recovered on cessation of treatment. Additionally, histological analysis of gill, liver, intestine, and kidney tissue revealed no toxicological effects.

Ethacridine lactate is a topical antiseptic, generally effective against Gram-positive bacteria and used to prevent wound infection in humans (Reinhardt et al., 2005). However, despite being used in therapeutic products (Table 3) nothing is known about its effectiveness as treatments for bacterial infections in fishes.

Copper sulphate is an inorganic salt with various antimicrobial properties, widely considered to be an effective antiparasitic and antifungal agent. It has been used in aquaculture for many years to combat pathogens such as *Piscinoodinium* spp., *Ichthyophthirius multifiliis,* and *Saprolegnia parasitica* (reviewed in Tavares-Dias, 2021). Comparatively little is known about its effectiveness as an antibacterial treatment for ornamentals but there is some evidence to suggest it could be used as a preventative treatment. In channel catfish, *Ictalurus punctatus*, 24 h exposure to copper sulphate (25 mg l^{-1}) prior to infection with *Edwardsiella ictaluri* reduced mortalities relative to untreated fish (Griffin and Mitchell, 2007). MICs of copper sulphate for a variety of pathogenic bacteria range from 100-1600 μg ml^{-1} (Benhalima et al., 2019), much higher than the 25 mg l^{-1} used by Griffin and Mitchell (2007), suggesting the effect was due to prior exposure rather than direct antibacterial effects.

Praziquental is an active ingredient often found in anthelmintic treatments for ornamental fishes (Table 3). A recent review has shown it has good efficacy against a number of cestode and monogenean fish pathogens in both food fish and ornamental species (Norbury et al., 2022). It is relatively safe to use, with toxic concentrations rarely reached during conventional therapy. However, there is limited evidence on its environmental impacts and there is potential for resistance to develop within targeted pathogens (Norbury et al., 2022).

Euthanasia

From a welfare perspective, in severe cases of disease, euthanasia may be the most ethical solution and should be carried out humanely. Overdose with a suitable waterborne anaesthetic (e.g. buffered tricaine methosulphate - MS 222) followed by destruction of the brain is frequently promoted as a humane method of euthanizing fishes (AVMA, 2020; Metcalfe and Craig, 2011; Sloman et al., 2019). However, options for the home aquarist can be limited due to the unavailability of anaesthetics to the general public in some countries. Clove oil appears to be most typically used by the home aquarist (Fernandes et al., 2017). Care should be taken to ensure the anaesthetic used is suitable for the fish species, as anaesthetics vary in efficacy, dosage, and perception by fishes in a species-specific manner and a ‘one size fits all’ approach should not be taken (Davis et al., 2015; Perret-Thiry et al., 2022; Readman et al., 2017).

Conclusion

The ornamental fish trade is a multi-billion dollar global industry with a responsibility for the welfare of a large number of fishes that are routinely traded internationally. With mortality and morbidity from disease resulting in significant detriment to fish welfare and economic losses for the industry, our review clearly highlights some large scientific gaps in our knowledge that require urgent attention. While the types of pathogens occurring in ornamental fishes are well-established, within commercial practices AMR is certainly a growing problem. Building on the previous systematic review in this field by Weir et al. (2012) we have shown that antimicrobial resistance is still an issue with many classes of antibiotics such as tetracyclines and penicillins proving ineffective treatments and some resistance being shown to previously effective antibiotics such as carbapenems. Inappropriate treatments of infections within the ornamental trade, particularly the use of antibiotics, will continue to fuel antimicrobial resistance with potential risks to human health. The paucity of *in vivo* studies on the efficacy of antibiotics in treating ornamental fish diseases makes it very difficult to make recommendations for commercial practice. Further research into efficacy to allow targeted treatment of fishes is clearly needed. We recommend collaboration between policy makers, stakeholders within the industry (e.g. ornamental fish producers and wholesalers) and environmental scientists to develop and implement international ‘One Health’ frameworks to curb the rise in AMR and reduce risks to human health.

Also concerning is the lack of scientific information surrounding the range of treatments available to most home aquarists to combat infections in their ornamental fishes. Our systematic review found minimal research into many of the commercial products available, and within that a predominance of *in vitro* rather than *in vivo* studies. Also lacking is consideration of the impacts of these treatments on general ornamental fish health and behaviour in order to fully evaluate the risks and benefits associated with these treatments. Many of the more traditional approaches such as salt and therapeutic dyes have significant side-effects. The emergence of AMR, coupled with a consumer demand for sustainable products highlights the need to develop further treatments that can be used throughout the trade to reduce disease and improve welfare. Ideal products for disease treatment in pet fishes should have high efficacy with minimal risk of resistance developing, be non-toxic to the fish with a significant margin between the effective dose and sub-lethal effects in the fish, such as adverse behavioural responses. More research is needed to understand fully these characteristics within existing treatments, but also into the potential for new treatments to reduce disease and improve ornamental fish welfare.

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References

Adel, Milad, Saeedi, A.A., Safari, R., Azizi, H.R., Adel, Mehrdad, 2013. *Pterophyllum scalare* (Perciformes: Cichlidae) A new paratenic host of *Capillaria* sp. (Nematoda: Capillariidae) in Iran. World J. Zool. 8, 371–375.

Ahmadniaye Motlagh, H., Safari, O., Selahvarzi, Y., Baghalian, A., Kia, E., 2020. Non-specific immunity promotion in response to garlic extract supplemented diets in female Guppy (*Poecilia reticulata*). Fish Shellfish Immunol. 97, 96–99.

Ahmed, I., Tiberi, S., Farooqi, J., Jabeen, K., Yeboah-Manu, D., Migliori, G.B., Hasan, R., 2020. Non-tuberculous mycobacterial infections—A neglected and emerging problem. Int. J. Infect. Dis. 92, S46–S50.

Alam, M., Rahman, M., Foysal, M., Hossain, M., 2011. Determination of lethal concentration and antibacterial activity of commonly used disinfectants. Int. J. Nat. Sci. 1, 102–105.

Altinok, I., 2004. Toxicity and therapeutic effects of chloramine-T for treating *Flavobacterium columnare* infection of goldfish. Aquaculture 239, 47–56.

Altinok, I., Grizzle, J.M., 2001. Effects of low salinities on *Flavobacterium columnare* infection of euryhaline and freshwater stenohaline fish. J. Fish Dis. 24, 361–367.

Ankri, S., Mirelman, D., 1999. Antimicrobial properties of allicin from garlic. Microbes Infect. 1, 125–129.

Ariel, E., 2005. Ornamental Fish as Trans-Boundary Vectors of Viral Diseases. In: Walker, P., Lester, R., Bondad-Reantaso, M.G. (Eds.), Diseases in Asian Aquaculture. Asian Fisheries Society, Manila, pp. 103–112.

Au-Yeung, C., Lam, K.-L., Chan, K.-W., Mo, W.-Y., 2022. Uses of antibiotics in ornamental fish in Hong Kong and the antibiotic resistance in the associated zoonotic pathogens. J. Xenobiotics 12, 365–377.

AVMA, 2020. American Veterinary Medical Association Guidelines For The Euthanasia of Animals: 2020 Edition.

Baldissera, M.D., Souza, C.F., Doleski, P.H., Santos, R.C.V., Raffin, R.P., Baldisserotto, B., 2018. Involvement of xanthine oxidase inhibition with the antioxidant property of nanoencapsulated *Melaleuca alternifolia* essential oil in fish experimentally infected with *Pseudomonas aeruginosa*. J. Fish Dis. 41, 791–796.

Baldissera, M.D., Souza, C.F., Júnior, G.B., de Vargas, A.C., Boligon, A.A., de Campos, M.M.A., Stefani, L.M., Baldisserotto, B., 2017. *Melaleuca alternifolia* essential oil enhances the non-specific immune system and prevents oxidative damage in *Rhamdia quelen* experimentally infected by *Aeromonas hydrophila*: Effects on cholinergic and purinergic systems in liver tissue. Fish Shellfish Immunol. 61, 1–8.

Barton, B.A., Iwama, G.K., 1991. Physiological changes in fish from stress in aquaculture with emphasis on the response and effects of corticosteroids. Annu. Rev. Fish Dis. 1, 3–26.

Baym, M., Lieberman, T.D., Kelsie, E.D., Chait, R., Gross, R., Yelin, I., Kishony, R., 2016. Spatiotemporal microbial evolution on antibiotic landscapes. Science (80-.). 353, 1147–1151.

Benhalima, L., Amri, S., Bensouilah, M., Ouzrout, R., 2019. Antibacterial effect of copper sulfate against multi-drug resistant nosocomial pathogens isolated from clinical samples. Pakistan J. Med. Sci. 35, 1322–1328.

Benhamed, S., Guardiola, F.A., Mars, M., Esteban, M.Á., 2014. Pathogen bacteria adhesion to skin mucus of fishes. Vet. Microbiol. 171, 1–12.

Biazus, A.H., Da, A.S., Bottari, N.B., Baldissera, M.D., Guilherme, M., Morsch, V.M., Rosa, M., Schetinger, C., Casagrande, R., Guarda, N.S., Moresco, R.N., Stefani, L.M., Campigotto, G., Boiago, M.M., 2017. Microbial Pathogenesis Fowl typhoid in laying hens cause hepatic oxidative stress. Microb. Pathog. 103, 162–166.

Bolivar, R.B., Aragones, M.A.D., Garcia, G.G., 2012. Effect of methylene blue and sodium chloride on the bacterial load in the transport water with nile tilapia (*Oreochromis niloticus* L.) fingerlings. Phil. Uni. J. Biol. Sci. 188–198.

Bouceiro-Mendes, R., Ortins-Pina, A., Fraga, A., Marques, T., Viveiros, M., Machado, D., Soares-de-Almeida, L., Freitas, J.P., Filipe, P., 2019. Mycobacterium marinum lymphocutaneous infection. Dermatol. Online J. 25, 0–5.

British Small Animal Veterinary Association, 2020. BSAVA Small Animal Formulary Part B: Exotic Pets.

Buján, N., Toranzo, A.E., Magariños, B., 2018. *Edwardsiella piscicida*: A significant bacterial pathogen of cultured fish. Dis. Aquat. Organ. 131, 59–71.

Cable, J., Tinsley, R.C., Harris, P.D., 2002. Survival, feeding and embryo development of *Gyrodactylus gasterostei* (Monogenea: Gyrodactylidae). Parasitology 124, 53–68.

Cabello, F.C., 2006. Heavy use of prophylactic antibiotics in aquaculture: A growing problem for human and animal health and for the environment. Environ. Microbiol. 8, 1137–1144.

Cardoso, P.H.M., Moreno, A.M., Moreno, L.Z., de Oliveira, C.H., Baroni, F. de A., Maganha, S.R. de L., de Sousa, R.L.M., Balian, S. de C., 2019. Infectious diseases in aquarium ornamental pet fish: Prevention and control measures. Brazilian J. Vet. Res. Anim. Sci. 56.

Cardoso, P.H.M., Moreno, L.Z., de Oliveira, C.H., Gomes, V.T.M., Silva, A.P.S., Barbosa, M.R.F., Sato, M.I.Z., Balian, S.C., Moreno, A.M., 2021. Main bacterial species causing clinical disease in ornamental freshwater fish in Brazil. Folia Microbiol. (Praha). 66, 231–

239.

Castro, V.S.P., Da Silva, A.S., Thom, G.R., Costa, M., Graça, D.L., Oliveira, D.C., Castro, J.L.C., Alves, S.H., Schetinger, M.R.C., Lopes, S.T.A., Stefani, L.M., Azevedo, M.I., Baldissera, M.D., Andrade, C.M., 2017. Microbial Pathogenesis Oxidative stress in rats experimentally infected by *Sporothrix schenckii* 107, 1–5.

CDC, 2020. Saving Lives By Taking a One Health Approach [Fact Sheet]. Cent. Dis. Control Prev.

Chambel, J., Costa, R., Gomes, M., Mendes, S., Baptista, T., Pedrosa, R., 2014. Hydrogen peroxide, iodine solution and methylene solution highly enhance the hatching rate of freshwater ornamental fish species. Aquac. Int. 22, 1743–1751.

Chan, F.T., Beatty, S.J., Gilles, A.S., Hill, J.E., Kozic, S., Luo, D., Morgan, D.L., Pavia, R.T.B., Therriault, T.W., Verreycken, H., Vilizzi, L., Wei, H., Yeo, D.C.J., Zeng, Y., Zięba, G., Copp, G.H., 2019. Leaving the fish bowl: the ornamental trade as a global vector for freshwater fish invasions. Aquat. Ecosyst. Heal. Manag. 22, 417–439.

Chatterjee, A., Ghosh, S., Bhattacharya, R., Chatterjee, S., Saha, N.C., 2020. A Comprehensive Review on the Prevalence and Dissemination of Some Bacterial Diseases in Ornamental Fishes and Their Preventive Measures. Sch. Acad. J. Biosci. 8, 371–377.

Chung, T.H., Yi, S.W., Shin, G.W., 2017. Antibiotic resistance and repetitive-element PCR fingerprinting in *Aeromonas veronii* isolates. J. Fish Dis. 40, 821–829.

Čížek, A., Dolejská, M., Sochorová, R., Strachotová, K., Piačková, V., Veselý, T., 2010. Antimicrobial resistance and its genetic determinants in aeromonads isolated in ornamental (koi) carp (*Cyprinus carpio* koi) and common carp (*Cyprinus carpio*). Vet. Microbiol. 142, 435–439.

Clark, R., Kupper, T., 2005. Old meets new: The interaction between innate and adaptive immunity. J. Invest. Dermatol. 125, 629–637.

Clinical and Laboratory Standards Institute (CLSI), 2022. Performance Standards for Antimicrobial Susceptibility Testing. 32nd ed. CLSI supplement M100. Clinical and Laboratory Standards Institute, USA.

Cole, B., Tamaru, C.S., Bailey, R., Brown, C., Ako, H., 1999. Shipping practices in the ornamental fish industry. Cent. Trop. Subtrop. Aquac. 1–25.

Collymore, C., Crim, M.J., Lieggi, C. 2016. Recommendations for health monitoring and reporting for zebrafish research facilities. Zebrafish 13, S138-148.

Da Silva, W.V., Ziemniczak, H.M., Bacha, F.B., Fernandes, R.B.S., Fujimoto, R.Y., Sousa, R.M., Saturnino, K.C., Honorato, C.A., 2021. Respiratory profile and gill histopathology of *Carassius auratus* exposed to different salinity concentrations. Semin. Agrar. 42, 2993–3005.

Dash, S., Das, S.K., Samal, J., Thatoi, H.N., 2018. Epidermal mucus, a major determinant in fish health: A review. Iran. J. Vet. Res. 19, 72–81.

Davis, D.J., Klug, J., Hankins, M., Doerr, H.M., Monticelli, S.R., Song, A., Gillespie, C.H., Bryda, E.C., 2015. Effects of clove oil as a euthanasia agent on blood collection efficiency and serum cortisol levels in Danio rerio. J. Am. Assoc. Lab. Anim. Sci. 54, 564–567.

Davis, R., Brown, P.D., 2016. Multiple antibiotic resistance index, fitness and virulence potential in respiratory *Pseudomonas aeruginosa* from Jamaica. J. Med. Microbiol. 65, 261–271.

De, N.C., 1999. On the development and life cycle of *Camallanus anabantis* (Nematoda: Camallanidae), a parasite of the climbing perch, *Anabas testudineus*. Folia Parasitol. (Praha). 46, 205–215.

De Lestang, P., Griffin, R., Allsop, Q., Grace, B.S., 2008. Effects of Two Different Landing Nets on Injuries to the *Barramundi Lates* calcarifer, an Iconic Australian Sport Fish. North Am. J. Fish. Manag. 28, 1911–1915.

Declercq, A.M., Haesebrouck, F., Van Den Broeck, W., Bossier, P., Decostere, A., 2013. Columnaris disease in fish: A review with emphasis on bacterium-host interactions. Vet. Res. 44, 1–17.

Declercq, A.M., Tilleman, L., Gansemans, Y., De Witte, C., Haesebrouck, F., Van Nieuwerburgh, F., Smet, A., Decostere, A., 2021. Comparative genomics of *Flavobacterium columnare* unveils novel insights in virulence and antimicrobial resistance mechanisms. Vet. Res. 52, 1–13.

Decostere, A., Ducatelle, R., Haesebrouck, F., 2002. Flavobacterium columnare (*Flexibacter columnaris*) associated with severe gill necrosis in koi carp (*Cyprinus carpio* L). Vet. Rec. 150, 694–695.

Decostere, A., Haesebrouck, F., Devriese, L.A., 1998. Characterization of four *Flavobacterium columnare* (Flexibacter columnaris) strains isolated from tropical fish. Vet. Microbiol. 62, 35–45.

Decostere, A., Hermans, K., Haesebrouck, F., 2004. Piscine mycobacteriosis: a literature review covering the agent and the disease it causes in fish and humans. Vet. Microbiol. 99, 159–166.

Delalay, G., Berezowski, J.A., Diserens, N., Schmidt-Posthaus, H., 2020. An understated danger: Antimicrobial resistance in aquaculture and pet fish in Switzerland, a retrospective study from 2000 to 2017. J. Fish Dis. 43, 1299–1315.

Dewi, R.R., Desrita, Fadhilla, A., 2018. The prevalence of parasites in ornamental fish from fish market in Medan. IOP Conf. Ser. Earth Environ. Sci. 122.

Dey, V.K., 2016. The global trade in ornamental fish. In: Infofish International 4/2016. infofish.org.

Dhanapala, P.M., Kalupahana, R.S., Kalupahana, A.W., Wijesekera, D.P.H., Kottawatta, S.A., Jayasekera, N.K., Silva-Fletcher, A., Jagoda, S.S.S.S., 2021. Characterization and antimicrobial resistance of environmental and clinical *Aeromonas* species isolated from fresh water ornamental fish and associated farming environment in Sri Lanka. Microorganisms 9.

Dharmaratnam, A., Swaminathan, T.R., Kumar, R., Basheer, V.S., 2018. Aeromonas hydrophila associated with mass mortality of adult goldfish carassius auratus (linnaeus, 1758) in ornamental farms in India. Indian J. Fish. 65, 116–126.

Dias, C., Mota, V., Martinez-Murcia, A., Saavedra, M.J., 2012. Antimicrobial resistance patterns of *Aeromonas* spp. isolated from ornamental fish. J. Aquac. Res. Dev. 3.

Dickerson, H.W., 2011. *Ichthyophthirius multifiliis*. In: Woo, P.T.K., Buchmann, K. (Eds.), Fish Parasites: Pathobiology and Protection. CABI, Wallingford, pp. 55–72.

Dikkeboom, A.L., Radi, C., Toohey-Kurth, K., Marcquenski, S., Engel, M., Goodwin, A.E., Way, K., Stone, D.M., Longshaw, C., 2004. First report of Spring Viremia of Carp Virus (SVCV) in wild common carp in North America. J. Aquat. Anim. Health 16, 169–178.

Dobiasova, H., Kutilova, I., Piackova, V., Vesely, T., Cizek, A., Dolejska, M., 2014. Ornamental fish as a source of plasmid-mediated quinolone resistance genes and antibiotic resistance plasmids. Vet. Microbiol. 171, 413–421.

Eissa, A.E., Abdelsalam, M., Tharwat, N., Zaki, M., 2013. Detection of *Saprolegnia parasitica* in eggs of angelfish *Pterophyllum scalare* (Cuvier-Valenciennes) with a history of decreased hatchability. Int. J. Vet. Sci. Med. 1, 7–14.

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

El-Hady, M.A., Samy, A.A., 2011. Molecular typing of *Pseudomonas* species isolated from some cultured fishes in Egypt. Glob. Vet. 7, 576–580.

Elliott, D.G., Shotts, E.B., 1980. Aetiology of an ulcerative disease in goldfish, *Carassius auratus* (L.): experimental induction of the disease. J. Fish Dis. 3, 145–151.

Emany, M.E., El-Sayed, M.E., Diab, A.S., Hassan, S.M., El-Gamal, R.M., 1995. Bacterial causes of fin rot in some fresh water fishes. Alexandria J. Vetinary Sci. 11, 535–547.

Eslamloo, K., Akhavan, S.R., Fallah, F.J., Henry, M.A., 2014. Variations of physiological and innate immunological responses in goldfish (*Carassius auratus*) subjected to recurrent acute stress. Fish Shellfish Immunol. 37, 147–153.

Estes, J.M., Altemara, M.L., Crim, M.J., Fletcher, C.A., Whitaker, J.W., 2021. Behavioral and reproductive effects of environmental enrichment and *Pseudoloma neurophilia* infection on adult zebrafish (*Danio rerio*). J. Am. Assoc. Lab. Anim. Sci. 60, 249–258.

Evans, B.B., Lester, R.J.G., 2001. Parasites of ornamental fish imported into Australia. Bull. Eur. Assoc. Fish Pathol. 21, 51–55.

Ezz EI Dien, N.M., Aly, S.M., EI Sayed, A.E., 1998. Outbreak of *Ichthyophthirius multifiliis* in ornamental goldfish (*Carassius auratus*) in Egypt. Egypt. J. Comp. Pathol. Clin. Pathol. 11, 235–244.

Fayed, A.A., Khater, A.A., Abboud, O.A., 1997. *Psuedomonas* septicaemia encountered in some ornamental fishes. Alexandria J. Vetinary Sci. 13.

Fernandes, I.M., Bastos, Y.F., Barreto, D.S., Lourenço, L.S., Penha, J.M., 2017. The efficacy of clove oil as an anaesthetic and in euthanasia procedure for small-sized tropical fishes. Brazilian J. Biol. 77, 444–450.

Ferraz, E., Sommerville, C., 1998. Pathology of *Piscinoodinium* sp. (Protozoa: Dinoflagellida), parasites of the ornamental freshwater catfishes *Corydoras* spp. and *Brochis splendens* (Pisces: Callichthyidae). Dis. Aquat. Organ. 33, 43–49.

Ferreira, M.M., Passador, R.J., Tavares-Dias, M., 2019. Community ecology of parasites in four species of *Corydoras* (Callichthyidae), ornamental fish endemic to the eastern amazon (Brazil). An. Acad. Bras. Cienc. 91, 1–13.

Florindo, M.C., Jerônimo, G.T., Steckert, L.D., Acchile, M., Figueredo, A.B., Gonçalves, E.L.T., Cardoso, L., Marchiori, N. da C., Assis, G. da C., Martins, M.L., 2017. Metazoan parasites of freshwater ornamental fishes. Lat. Am. J. Aquat. Res. 45, 992–998.

Forwood, J.M., Harris, J.O., Deveney, M.R., 2013. Efficacy of bath and orally administered praziquantel and fenbendazole against *Lepidotrema bidyana* Murray, a monogenean parasite of silver perch, *Bidyanus bidyanus* (Mitchell). J. Fish Dis. 36, 939–947.

Foster, F.J., Woodbury, L., 1936. The use of malachite green as a fish fungicide and antiseptic. Progress. Fish-Culturist 3, 7–9.

Fouz, B., Devesa, S., Gravningen, K., Barja, J.L., Toranzo, A.E., 1990. Antibacterial action of the mucus of turbot. Bull. Eur. Assoc. Fish Pathol. 10, 56–59.

Francis-floyd, R., Yanong, R., Pouder, D., 2016. *Ichthyophthirius multifiliis* (White Spot) Infections in Fish. IFAS Ext. Univ. Florida 1–5.

Fridman, S., Sinai, T., Zilberg, D., 2014. Efficacy of garlic based treatments against monogenean parasites infecting the guppy (*Poecilia reticulata* (Peters)). Vet. Parasitol. 203, 51–58.

Gan, H., He, H., Sato, A., Hatta, H., Nakao, M., Somamoto, T., 2015. Ulcer disease prophylaxis in koi carp by bath immersion with chicken egg yolk containing anti-*Aeromonas salmonicida* IgY. Res. Vet. Sci. 99, 82–86.

Gao, Y., Chen, Z., Yao, W., Li, D., Fu, X., 2021. Gentamicin Combined With Hypoionic Shock Rapidly Eradicates Aquaculture Bacteria in vitro and in vivo. Front. Microbiol. 12, 1–10.

Gauthier, D.T., 2015. Bacterial zoonoses of fishes: A review and appraisal of evidence for linkages between fish and human infections. Vet. J. 203, 27–35.

Gauthier, D.T., Rhodes, M.W., 2009. Mycobacteriosis in fishes: A review. Vet. J. 180, 33–47.

Gholipour-Kanani, H., Sahandi, J., Taheri, A., 2012. Influence of Garlic (*Allium sativum*) and Mother worth (*Matricaria chamomilla*) Extract on *Ichthyophtirius multifilus* Parasite Treatment in Sail Fin Molly (*Poecilia latipinna*) Ornamental Fish. APCBEE Procedia 4, 6–11.

Gomez, D., Sunyer, J., Salinas, I., 2013. The mucosal immune system of fish: the evolution of tolerating commensals while fighting pathogens. Fish Shellfish Immunol. 35, 1729–1739.

Gormez, O., Diler, O., 2014. In vitro Antifungal activity of essential oils from *Tymbra, Origanum*, *Satureja* species and some pure compounds on the fish pathogenic fungus, *Saprolegnia parasitica.* Aquac. Res. 45, 1196–1201.

Gozlan, R.E., Marshall, W.L., Lilje, O., Jessop, C.N., Gleason, F.H., Andreou, D., 2014. Current ecological understanding of fungal-like pathogens of fish: What lies beneath? Front. Microbiol. 5, 1–16.

Griffin, B.R., Mitchell, A.J., 2007. Susceptibility of channel catfish, *Ictalurus punctatus* (Rafinesque), to *Edwardsiella ictaluri* challenge following copper sulphate exposure. J. Fish Dis. 30, 581–585.

Guz, L., Puk, K., 2022. Antibiotic susceptibility of mycobacteria isolated from ornamental fish. J. Vet. Res. 66, 69–76.

Haenen, O., Karunasagar, Iddya, Manfrin, A., Zrncic, S., Lavilla-Pitogo, C., Lawrence, M., Hanson, L., Subasinghe, R., Bondad-Reantaso, M.G., Karunasagar, Indrani, 2020a. Contact-zoonotic bacteria of warmwater ornamental and cultured fish. Asian Fish. Sci. 33, 39–45.

Haenen, O., Veldman, K., Ceccarelli, D., Tafro, N., Zuidema, T., Mevius, D., 2020. Potential transfer of antimicrobial resistance and zoonotic bacteria through global ornamental fish trade. Asian Fish. Sci. 33, 46–54.

Haroon, F., Iqbal, Z., Pervaiz, K., Khalid, A.N., 2014. Incidence of fungal infection of freshwater ornamental fish in pakistan. Int. J. Agric. Biol. 16, 411–415.

Hawke, J.P., Kent, M., Rogge, M., Baumgartner, W., Wiles, J., Shelley, J., Christine Savolainen, L., Wagner, R., Murray, K., Peterson, T.S., 2013. Edwardsiellosis caused by Edwardsiella ictaluri in laboratory populations of Zebrafish Danio rerio. J. Aquat. Anim. Health 25, 171–183.

Hawke, J.P., McWhorter, A.C., Steigerwalt, A.G., Brenner, D.J., 1981. *Edwardsiella ictaluri* sp. nov., the causative agent of enteric septicemia of catfish. Int. J. Syst. Bacteriol. 31, 396–400.

Homer, L.E., Leach, D.N., Lea, D., Lee, L.S., Henry, R.J., Baverstock, P.R., 2000. Natural variation in the essential oil content of *Melaleuca alternifolia* Cheel (Myrtaceae) 28.

Horefti, E., 2023. The Importance of the One Health Concept in Combating Zoonoses. Pathogens 12.

Hossain, S., Dahanayake, P.S., De Silva, B.C.J., Wickramanayake, M.V.K.S., Wimalasena, S.H.M.P., Heo, G.J., 2019a. Multidrug resistant *Aeromonas* spp. isolated from zebrafish (*Danio rerio*): antibiogram, antimicrobial resistance genes and class 1 integron gene cassettes. Lett. Appl. Microbiol. 68, 370–377.

Hossain, S., De Silva, B.C.J., Wickramanayake, M.V.K.S., Dahanayake, P.S., Wimalasena, S.H.M.P., Heo, G.J., 2019b. Incidence of antimicrobial resistance genes and class 1 integron gene cassettes in multidrug-resistant motile *Aeromonas* sp. isolated from ornamental guppy (*Poecilia reticulata*). Lett. Appl. Microbiol. 69, 2–10.

Hossain, S., De Silva, B.C.J., Wimalasena, S.H.M.P., Pathirana, H.N.K.S., Dahanayake, P.S., Heo, G.J., 2018. Distribution of antimicrobial resistance genes and class 1 integron gene cassette arrays in motile *Aeromonas* spp. Isolated from goldfish (*Carassius auratus*). Microb. Drug Resist. 24, 1217–1225.

Hossain, S., De Silva, B.C.J., Wimalasena, S.H.M.P., Pathirana, H.N.K.S., Dahanayake, P.S., Heo, G.J., 2019c. Characterization of virulence determinants and multiple antimicrobial resistance profiles in motile *Aeromonas* spp. isolated from ornamental goldfish (*Carassius auratus*). J. Exot. Pet Med. 29, 51–62.

Hossain, S., Heo, G.J., 2021. Ornamental fish: a potential source of pathogenic and multidrug-resistant motile Aeromonas spp. Lett. Appl. Microbiol. 72, 2–12.

Howe, G.E., Stehly, G.R., 1998. Experimental infection of rainbow trout with *Saprolegnia parasitica*. J. Aquat. Anim. Health 10, 397–404.

Huang, Y., Xu, X., Liu, Y., Wu, K., Zhang, W., Liu, P., Zeng, X., Sun, J., Jiang, Y., Wang, H., 2012. Successful treatment of refractory cutaneous infection caused by Mycobacterium marinum with a combined regimen containing amikacin. Clin. Interv. Aging 7, 533–538.

Idrus, S., Radiena, M.S., Sumarsana, Smith, H., 2020. Quality and Chemical Composition of Cajuput Oil from Moluccas and Papua. In: Journal of Physics: Conference Series.

Intorre, L., Meucci, V., Di Bello, D., Monni, G., Soldani, G., Pretti, C., 2007. Tolerance of benzalkonium chloride, formalin, malachite green, and potassium permanganate in goldfish and zebrafish. J. Am. Vet. Med. Assoc. 231, 590–595.

Iqbal, M.C., Shalij, P.., 2019. Supply Chain Risk Assessment in the Ornamental Fish Supply Chain. Int. J. Syst. Dyn. Appl. 8, 36–50.

Iqbal, Z., Haroon, F., 2014. Parasitic infections of some freshwater ornamental fishes imported in Pakistan. Pak. J. Zool. 46, 651–656.

Iqbal, Z., Sajjad, R., 2013. Some pathogenic fungi parasitizing two exotic tropical ornamental fishes. Int. J. Agric. Biol. 15, 595–598.

Jagoda, S.S.S. de S., Wijewardana, T.G., Arulkanthan, A., Igarashi, Y., Tan, E., Kinoshita, S., Watabe, S., Asakawa, S., 2014. Characterization and antimicrobial susceptibility of motile aeromonads isolated from freshwater ornamental fish showing signs of septicaemia. Dis. Aquat. Organ. 109, 127–137.

Jaktaji, R.P., Mohiti, E., 2010. Study of mutations in the DNA gyrase gyrA gene of *Escherichia coli*. Iran. J. Pharm. Res. 9, 43–48.

Jangaran Nejad, A., Peyghan, R., Varzi, H.N., Shahriyari, A., 2017. Florfenicol pharmacokinetics following intravenous and oral administrations and its elimination after oral and bath administrations in common carp (*Cyprinus carpio*). Vet. Res. Forum 8, 327–331.

Jaruboonyakorn, P., Tejangkura, T., Chontananarth, T., 2022. Multiplex PCR development for the simultaneous and rapid detection of two pathogenic flukes, *Dactylogyrus* spp. and *Centrocestus formosanus*, in ornamental fishes. Aquaculture 548, 737660.

Jiang, N., Yuan, D., Zhang, M., Luo, L., Wang, N., Xing, W., Li, T., Huang, X., Ma, Z., 2020. Diagnostic case report: Disease outbreak induced by CyHV-2 in goldfish in China. Aquaculture 523, 735156.

Johnson, A.K., 1961. Ichthyophthiriasis in a Recirculating Closed - Water Hatchery. Progress. Fish-Culturist 23, 79–82.

Jones, M., Alexander, M.E., Snellgrove, D., Smith, P., Bramhall, S., Carey, P., Henriquez, F.L., McLellan, I., Sloman, K.A., 2021. How should we monitor welfare in the ornamental fish trade? Rev. Aquac. 1–21.

Julinta, R.B., Roy, A., Singha, J., Abraham, T.J., Patil, P.K., 2017. Evaluation of Efficacy of Oxytetracycline Oral and Bath Therapies in Nile Tilapia, *Oreochromis niloticus* against *Aeromonas hydrophila* Infection. Int. J. Curr. Microbiol. Appl. Sci. 6, 62–76.

Kent, M.L., Sanders, J.L., 2020. Important parasites of zebrafish in research facilities. In: The Zebrafish in Biomedical Research: Biology, Husbandry, Diseases, and Research Applications. Elsevier, pp. 479–494.

Kent, M.L., Watral, V., Gaulke, C.A., Sharpton, T.J., 2019. Further evaluation of the efficacy of emamectin benzoate for treating *Pseudocapillaria tomentosa* (Dujardin 1843) in zebrafish *Danio rerio* (Hamilton 1822). J. Fish Dis. 42, 1351–1357.

Khan, Z.A., Siddiqui, M.F., Park, S., 2019. Current and emerging methods of antibiotic susceptibility testing. Diagnostics 9.

Khoo, L., 2000. Fungal diseases in fish. Semin. Avian Exot. Pet Med. 9, 102–111.

Kim, J.H., Hayward, C.J., Heo, G.J., 2002. Nematode worm infections (*Camallanus cotti*, Camallanidae) in guppies (*Poecilia reticulata*) imported to Korea. Aquaculture 205, 231–235.

Kim, J., Lee, Y.-S., Lee, S.-G., Shin, S.-C., Park, I.-K., 2008. Fumigant antifungal activity of plant essential oils and components from West Indian bay (*Pimenta racemosa*) and thyme (*Thymus vulgaris*) oils against two phytopathogenic fungi. Flavour Fragr. J. 23, 272–277.

King, T.A., 2019. Wild caught ornamental fish: a perspective from the UK ornamental aquatic industry on the sustainability of aquatic organisms and livelihoods. J. Fish Biol. 94, 925–936.

Klfack, S., Schröder, L., Jin, Y., Lenk, M., Lee, P.-Y., Fuchs, W., Avarre, J.-C., Bergmann, S.M. (2022). Development of an attenuated vaccine against Koi Herpesvirus Disease (KHVD) suitable for oral administration and immersion. npj Vaccines 7, 106.

Kumar, G., Byars, T.S., Greenway, T.E., Aarattuthodiyil, S., Khoo, L.H., Griffin, M.J., Wise, D.J., 2019. Economic assessment of commercial-scale *Edwardsiella ictaluri* vaccine trials in U.S. catfish industry. Aquac. Econ. Manag. 23, 254–275.

Kumar, R., Swaminathan, T.R., Kumar, R.G., Dharmaratnam, A., Basheer, V.S., Jena, J.K., 2015. Mass mortality in ornamental fish, Cyprinus carpio koi caused by a bacterial pathogen, Proteus hauseri. Acta Trop. 149, 128–134.

Kümmerer, K., 2009. Antibiotics in the aquatic environment - A review - Part I. Chemosphere 75, 417–434.

Kušar, D., Zajc, U., Jenčič, V., Ocepek, M., Higgins, J., Žolnir-Dovč, M., Pate, M., 2017. Mycobacteria in aquarium fish: results of a 3-year survey indicate caution required in handling pet-shop fish. J. Fish Dis. 40, 773–784.

Lahnsteiner, F., Weismann, T., 2007. Treatment of ichthyophthiriasis in rainbow trout and common carp with common and alternative therapeutics. J. Aquat. Anim. Health 19, 186–194.

Lavin, E.S., Getchell, R.G., Daugherity, E.K., Kent, M.L., Frosolone, A.D., Ivanek, R., 2023. Assessment of oral albendazole and fumagillin in the treatment of *Pseudoloma neurophilia* in adult zebrafish. Comp. Med. 73, 335–345.

Lazado, C.C., Fridman, S., Sinai, T., Zilberg, D., 2018. First report of *Streptococcus parauberis* in a cultured freshwater ornamental fish, the ram cichlid *Mikrogeophagus ramirezi* (Myers & Harry, 1948). J. Fish Dis. 41, 161–164.

Lee, Y., Robbins, N., Cowen, L.E., 2023. Molecular mechanisms governing antifungal drug resistance. Antimicrob. Resist. 1, 1–9.

Levsen, A., 2001. Transmission ecology and larval behaviour of *Camallanus cotti* (Nematoda, Camallanidae) under aquarium conditions. Aquarium Sci. Conserv. 3, 315–325.

Lewbart, G., Vaden, S., Deen, J., Manaugh, C., Whitt, D., Doi, A., Smith, T., Flammer, K., 1997. Pharmacokinetics of enrofloxacin in the red pacu (*Colossoma brachypomum*) after intramuscular, oral and bath administration. J. Vet. Pharmacol. Ther. 20, 124–128.

Lewbart, G.A., 2001. Bacteria and ornamental fish. Semin. Avian Exot. Pet Med. 10, 48–56.

Li, X.Z., Livermore, D.M., Nikaido, H., 1994. Role of efflux pump(s) in intrinsic resistance of *Pseudomonas aeruginosa*: Resistance to tetracycline, chloramphenicol, and norfloxacin. Antimicrob. Agents Chemother. 38, 1732–1741.

Li, X.Z., Nikaido, H., 2009. Efflux-Mediated Drug Resistance in Bacteria: An Update. Drugs

69, 1555–1623.

Lieke, T., Meinelt, T., Hoseinifar, S.H., Pan, B., Straus, D.L., Steinberg, C.E.W., 2020. Sustainable aquaculture requires environmental-friendly treatment strategies for fish diseases. Rev. Aquac. 12, 943–965.

Liu, X., Wang, H., Zhao, H., 2021. Prevalence of antibiotic resistance genes in wastewater collected from ornamental fish market in northern China. Environ. Pollut. 271, 116316.

Loh, R., 2015. Treatment modalities and medications used in tropical fish and koi diseases. In *40th World Small Animal Veterinary Association Congress, Bangkok, Thailand, 15-18 May, 2015. Proceedings book* (pp. 766-768). World Small Animal Veterinary Association.

Lupo, A., Coyne, S., Berendonk, T.U., 2012. Origin and evolution of antibiotic resistance: The common mechanisms of emergence and spread in water bodies. Front. Microbiol. 3, 1–13.

Luz, R.K., Martínez-Álvarez, R.M., De Pedro, N., Delgado, M.J., 2008. Growth, food intake regulation and metabolic adaptations in goldfish (*Carassius auratus*) exposed to different salinities. Aquaculture 276, 171–178.

Maceda-Veiga, A., Cable, J., 2014. Efficacy of sea salt, metronidazole and formalin-malachite green baths in treating *Icthyophthirius multifiliis* infections of mollies (*Poecilia sphenops*). Bull. Eur. Assoc. Fish Pathol. 34, 182–186.

Mahrt, N., Tietze, A., Künzel, S., Franzenburg, S., Barbosa, C., Jansen, G., Schulenburg, H., 2021. Bottleneck size and selection level reproducibly impact evolution of antibiotic resistance. Nat. Ecol. Evol. 5, 1233–1242.

Mamun, M.A. Al, Nasren, S., Rathore, S.S., Rahman, M.M., 2021. Mass infection of *Ichthyophthirius multifiliis* in two ornamental fish and their control measures. Ann. Biol. 37, 209–214.

Mamun, M.A.A., Nasren, S., Srinivasa, K.H., Rathore, S.S., Abhiman, P.B., Rakesh, K., 2020. Heavy infection of *Ichthyophthirius multifiliis* in striped catfish (*Pangasianodon hypophthalmus*, Sauvage 1878) and its treatment trial by different therapeutic agents in a control environment. J. Appl. Aquac. 32, 81–93.

Marking, L.L., Howe, G.E., Crowther, J.R., 1988. Toxicity of Erythromycin, Oxytetracycline, and Tetracycline Administered to Lake Trout in Water Baths, by Injection, or by Feeding. N. Am. J. Aquac. 50, 197–201.

Martins, M.L., Garcia, F., Piazza, R.S., Ghiraldelli, L., 2007. *Camallanus maculatus* n. sp. (Nematoda: Camallanidae) in an ornamental fish *Xiphophorus maculatus* (Osteichthyes: Poeciliidae) cultivated in São Paulo State, Brazil. Arq. Bras. Med. Vet. e Zootec. 59, 1224–1230.

Mashima, T.Y., Lewbart, G.A., 2000. Pet fish formulary. Vet. Clin. North Am. Exot. Anim. Pract. 3, 117–130.

Masud, N., Ellison, A., Cable, J., 2019. A neglected fish stressor: Mechanical disturbance during transportation impacts susceptibility to disease in a globally important ornamental fish. Dis. Aquat. Organ. 134, 25–32.

Mateus, A.P., Anjos, L., Cardoso, J.R., Power, D.M., 2017. Chronic stress impairs the local immune response during cutaneous repair in gilthead sea bream (*Sparus aurata*, L.). Mol. Immunol. 87, 267–283.

Matthews, R.A., 2005. *Ichthyophthirius multifiliis* fouquet and ichthyophthiriosis in freshwater teleosts. Adv. Parasitol. 59, 159–241.

McDermott, C., Palmeiro, B., 2020. Updates on Selected Emerging Infectious Diseases of Ornamental Fish. Vet. Clin. North Am. - Exot. Anim. Pract. 23, 413–428.

McHale, D., Laurie, W.A., Woof, M.A., 1977. Composition of West Indian bay oils. Food Chem. 2, 19–25.

Meinelt, T., Rose, A., Pietrock, M., 2002. Effects of calcium content and humic substances on the toxicity of acriflavine to juvenile zebrafish *Danio rerio*. J. Aquat. Anim. Health 14, 35–38.

Metcalfe, J.D., Craig, J.F., 2011. Ethical justification for the use and treatment of fishes in research: An update. J. Fish Biol. 78, 393–394.

Midttun, H.L.E., Vindas, M.A., Nadler, L.E., Øverli, Ø., Johansen, I.B., 2020. Behavioural effects of the common brain-infecting parasite *Pseudoloma neurophilia* in laboratory zebrafish (*Danio rerio*). Sci. Rep. 10, 1–9.

Mocho, J.-P., 2016. Three-dimensional screen: a comprehensive approach to the health monitoring of zebrafish. Zebrafish 13, S132-S137.

Mohamed, A., Mohamed, A.M., Ismaiel, M.M., Kenawy, A.M., Abd El-Ghany, O.A., 2010. Impact of experimental infection with *Gyrodactylus* species on the density of skin mucus in fries of catfish (*Clarias gariepinus*) with emphasis on the pathological changes. Glob. Vet. 4, 67–73.

Mohammadi, F., Mousavi, S.M., Rezaie, A., 2012. Histopathological study of parasitic infestation of skin and gill on oscar (*Astronotus ocellatus*) and discus (*Symphysodon discus*). AACL Bioflux 5, 88–93.

Molokomme, P.S., Benovics, M., Luus-Powell, W.J., Lukhele, L.P., Přikrylová, I., 2023. *Dactylogyrus* spp. (Dactylogyridae, Monogenea) from tinfoil barb, *Barbonymus schwanenfeldii* imported into South Africa: morphometric and molecular characterisation. Parasite 30.

Mousavi, H.A.E., Omidzahir, S., Soltani, M., Shayan, P., Ebrahimzadeh, E., Mousavi, S., Hoseini, M., 2013. Morphometrical and molecular characterization of *Gyrodactylus cichlidarum* (Gyrodactylidae) from *Astronotus ocellatus* (Cichlidae) in Iran. Comp. Clin. Path. 22, 1093–1097.

Munson, A., Bifi, A.G., Campos, D., Mccoll, D., Wong, M., Yeomans, W.E., Killen, S.S., 2024. First records of the introduced sailfin catfish Pterygoplichthys in the United Kingdom. BioInvasions Rec. 13, 241–250.

Murray, I.A., Shaw, W. V., 1997. O-Acetyltransferases for chloramphenicol and other natural products. Antimicrob. Agents Chemother. 41, 1–6.

My, N.T.K., Dung, T.T., Rodkhum, C., Ha, D.T., 2020. Effect of sodium chloride and temperature on biofilm formation and virulence of *Flavobacterium columnare* isolated from striped catfish (*Pangasianodon hypophthalmus*). Can Tho Univ. J. Sci. 12, 66–72.

Nardoni, S., Najar, B., Fronte, B., Pistelli, L., Mancianti, F., 2019. In vitro activity of essential oils against *Saprolegnia parasitica*. Molecules 24, 6–13.

Narendrakumar, L., Geetha Preena, P., Swaminathan, T.R., 2023. Antimicrobial resistance in ornamental fisheries: Causes and preventive measures. In: Mothadaka, M.P., Vaiyapuri, M., Rao Badireddy, M., Nagarajrao Ravishankar, C., Bhatia, R., Jena, J. (eds) Handbook on Antimicrobial Resistance. Springer, Singapore. https://doi.org/10.1007/978-981-16-

9723-4_9-1

Noga, E.J., 2010. Fish Disease: Diagnosis and Treatment, 2nd ed. ed. Wiley-Blackwell.

Norbury, L.J., Shirakashi, S., Power, C., Nowak, B.F., Bott, N.J., 2022. Praziquantel use in aquaculture – Current status and emerging issues. Int. J. Parasitol. Drugs Drug Resist. 18, 87–102.

OATA, 2018. EU ornamental fish import & export statistics 2017 (Third countries & intra-EU community trade). Ornam. Aquat. Trade Assoc.

OATA, 2020. Fishing for Facts. Available at: https://ornamentalfish.org/wp-content/uploads/Fishing-for-facts-report-ONLINE-SPREADS.pdf

Olivier, K., 2003. World trade in ornamental species. In: Cato, J.C., Brown, C.L. (Eds.), Marine Ornamental Species: Collection, Culture & Conservation. Wiley-Blackwell, pp. 49–64.

Ordóñez-Grande, B., Fernández-Alacid, L., Sanahuja, I., Sánchez-Nuño, S., Fernández-Borràs, J., Blasco, J., Ibarz, A., 2020. Evaluating mucus exudation dynamics through isotopic enrichment and turnover of skin mucus fractions in a marine fish model. Conserv. Physiol. 8, 1–11.

Page, M.J., McKenzie, J.E., Bossuyt, P.M., Boutron, I., Hoffmann, T.C., Mulrow, C.D., Shamseer, L., Tetzlaff, J.M., Akl, E.A., Brennan, S.E., Chou, R., Glanville, J., Grimshaw, J.M., Hróbjartsson, A., Lalu, M.M., Li, T., Loder, E.W., Mayo-Wilson, E., McDonald, S., McGuinness, L.A., Stewart, L.A., Thomas, J., Tricco, A.C., Welch, V.A., Whiting, P., Moher, D., 2021. The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. BMJ 372.

Palmeiro, B.S., Roberts, H.E., 2012. Fish: Gastrointestinal nematode and cestode parasites. In: Mayer, J., Donnelly, T.M. (Eds.), Clinical Veterinary Advisor: Birds and Exotic Pets. Saunders, pp. 27–28.

Perret-Thiry, C., Raulic, J., Vergneau-Grosset, C., 2022. Evaluation of prolonged immersion in tricaine methanesulfonate for juvenile goldfish (Carassius auratus) euthanasia. J. Am. Vet. Med. Assoc. 260, 911–915.

Phillips Savage, A.C.N., Blake, L., Suepaul, R., McHugh, O., Rodgers, R., Thomas, C., Oura, C., Soto, E., 2022. Piscine mycobacteriosis in the ornamental fish trade in Trinidad and Tobago. J. Fish Dis. 45, 547–560.

Piewbang, C., Wardhani, S.W., Sirivisoot, S., Surachetpong, W., Sirimanapong, W., Kasantikul, T., Techangamsuwan, S., 2024. First report of natural Cyprinid herpesvirus-2 infection associated with fatal outbreaks of goldfish (Carassius auratus) farms in Thailand. Aquaculture 581, 740481.

Picón-Camacho, S.M., Marcos-Lopez, M., Bron, J.E., Shinn, A.P., 2012. 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, Parasitology.

Plakas, S.M., Doerge, D.R., Turnipseed, S.B., 1999. Disposition and metabolism of malachite green and other therapeutic dyes in fish. In: Smith, D.J., Gingerich, W.H., Beconi-Barker, M.G. (Eds.), Xenobiotics in Fish. Kluwer Academic/Plenum Publishers, New York, pp. 149–166.

Preena, P.G., Arathi, D., Raj, N.S., Arun Kumar, T. V., Arun Raja, S., Reshma, R.N., Raja Swaminathan, T., 2020a. Diversity of antimicrobial-resistant pathogens from a freshwater ornamental fish farm. Lett. Appl. Microbiol. 71, 108–116.

Preena, P.G., Swaminathan, T.R., Kumar, V.J.R., Singh, I.S.B., 2020b. Antimicrobial resistance in aquaculture: a crisis for concern. Biologia 75, 1497-1517.

Preena, P.G., Dharmaratnam, A., Raj, N.S., Raja, S.A., Nair, R.R., Swaminathan, T.R., 2021. Antibiotic-resistant Enterobacteriaceae from diseased freshwater goldfish. Arch. Microbiol. 203, 219–231.

Puk, K., Guz, L., 2020. Occurrence of *Mycobacterium* spp. In ornamental fish. Ann. Agric. Environ. Med. 27, 535–539.

Quinn, J.P., Dudek, E.J., Divincenzo, C.A., Lucks, D.A., Lerner, S.A., 1986. Emergence of resistance to imipenem during therapy for *Pseudomonas aeruginosa* infections. J. Infect. Dis. 154, 289–294.

Rahmati-Holasoo, H., Marandi, A., Mousavi, H.E., Azizi, A., 2023. Isolation and identification of *Capillaria* sp. in ornamental green terror (*Andinoacara rivulatus* Günther, 1860) farmed in Iran. Bull. Eur. Assoc. Fish Pathol. 43, 12–20.

Raissy, M., Zandi, S., Ahmadi, A., Foroutan, M.S., Fadaeifard, F., 2012. Experimental evaluation of pathogenicity of *Streptococcus iniae* in Silver Shark and Rainbow Shark. African J. Microbiol. Res. 6, 3560–3563.

Raj, V.S., Fournier, G., Rakus, K., Ronsmans, M., Ouyang, P., Michel, B., Delforges, C., Costes, B., Farnir, F., Leroy, B., Wattiez, R., Melard, C., Mast, J., Lieffrig, F., Vanderplasschen, A., 2011. Skin mucus of *Cyprinus carpio* inhibits cyprinid herpesvirus 3 binding to epidermal cells. Vet. Res. 42.

Rao, M.V., Kumar, T.A., Haq, M.B., 2013. Diseases In The Aquarium Fishes: Challenges And Areas Of Concern: An Overview. Int. J. Environ. 2, 127–146.

Readman, G.D., Owen, S.F., Knowles, T.G., Murrell, J.C., 2017. Species specific anaesthetics for fish anaesthesia and euthanasia. Sci. Rep. 7, 1–7.

Reinhardt, C.S., Geske, T., Schmolz, M., 2005. A topical wound disinfectant (ethacridine lactate) differentially affects the production of immunoregulatory cytokines in human whole-blood cultures. Wounds 17, 213–221.

Reygaert, W.C., 2018. An overview of the antimicrobial resistance mechanisms of bacteria. AIMS Microbiol. 4, 482–501.

Roberts, H.E., Palmeiro, B., Weber, E.S., 2009. Bacterial and Parasitic Diseases of Pet Fish. Vet. Clin. North Am. - Exot. Anim. Pract. 12, 609–638.

Rolinson, G.N., 1998. Forty years of β-lactam research. J. Antimicrob. Chemother. 41, 589–603.

Rose, S., Hill, R., Bermudez, L.E., Miller-Morgan, T., 2013. Imported ornamental fish are colonized with antibiotic-resistant bacteria. J. Fish Dis. 36, 533–542.

Russo, R., Mitchell, H., Yanong, R.P.E., 2006. Characterization of *Streptococcus iniae* isolated from ornamental cyprinid fishes and development of challenge models. Aquaculture 256, 105–110.

Saengsitthisak, B., Chaisri, W., Punyapornwithaya, V., Mektrirat, R., Klayraung, S., Bernard, J.K., Pikulkaew, S., 2020. Occurrence and antimicrobial susceptibility profiles of multidrug-resistant aeromonads isolated from freshwater ornamental fish in chiang mai province. Pathogens 9, 1–13.

Saha, M., Bandyopadhyay, P.K., 2017. Phytochemical screening for identification of bioactive compound and antiprotozoan activity of fresh garlic bulb over trichodinid ciliates affecting ornamental goldfish. Aquaculture 473, 181–190.

Sahandi, J., Bagherzadeh Lakani, F., Zorriehzahra, M.J., Shohreh, P., 2023. Effects of garlic (*Allium sativum*) and chamomile (*Matricaria chamomilla*) extracts on *Ichthyophthirius* multifiliis parasite in guppy fish (*Poecilia reticulata*). J. Surv. Fish. Sci. 10, 18–28.

Said, A.E., 2008. Light and electron microscopic studies on the feeding organ of the adult monogenean gill parasite *Dactylogyrus extensus* dactylogyridae. J. Egypt. Ger. Soc. Zool. 54(C), 149–163.

Sampaio, F.D.F., Freire, C.A., 2016. An overview of stress physiology of fish transport: changes in water quality as a function of transport duration. Fish Fish. 17, 1055–1072.

Sanders, J.L., Lawrence, C., Nichols, D.K., Brubaker, J.F., Peterson, T.S., Murray, K.N., Kent, M.L., 2010. *Pleistophora hyphessobryconis* (Microsporidia) infecting zebrafish *Danio rerio* in research facilities. Dis. Aquat. Organ. 91, 47–56.

Sanders, J.L., Monteiro, J.F., Martins, S., Certal, A.C., Kent, M.L., 2020. The impact of *Pseudoloma neurophilia* infection on body condition of zebrafish. Zebrafish 17, 139–146.

Santos, M.E., Lopes, J.F., Kratochwil, C.F., 2023. East African cichlid fishes. Evodevo 14, 1–21.

Santos, L., Ramos, F., 2018. Antimicrobial resistance in aquaculture: Current knowledge and alternatives to tackle the problem. Int. J. Antimicrob. Agents 52, 135–143.

Sasmal, D., Banerjee, T., Bandyopadhyaya, S., Abraham, T.J., 2004. Antibiotic sensitivity of bacterial flora associated with ornamental fish. Indian J. Fish. 51, 245–249.

Sasmal, D., Surendra Babu, C., Jawahar Abraham, T., 2005. Effect of garlic (*Allium sativum*) extract on the growth and disease resistance of *Carassius auratus* (Linnaeus, 1758). Indian J. Fish 207–214.

Schelkle, B., Doetjes, R., Cable, J., 2011. The salt myth revealed: Treatment of gyrodactylid infections on ornamental guppies, *Poecilia reticulata*. Aquaculture 311, 74–79.

Schelkle, B., Snellgrove, D., Cable, J., 2013. In vitro and in vivo efficacy of garlic compounds against Gyrodactylus turnbulli infecting the guppy (*Poecilia reticulata*). Vet. Parasitol. 198, 96–101.

Schelkle, B., Richards, E.L., Snellgrove, D., Cable, J., 2015a. Cajeput oil, an effective botanical against gyrodactylid infection. Aquac. Res. 47, 1–9.

Schelkle, B., Snellgrove, D., Jones, L.L., Cable, J., 2015b. Efficacy of commercially available products against *Gyrodactylus turnbulli* infections on guppies *Poecilia reticulata*. Dis. Aquat. Organ. 115, 129–137.

Scott, M.E., 1982. Reproductive potential of *Gyrodactylus bullatarudis* (Monogenea) on guppies (*Poecilia reticulata*). Parasitology 85, 217–236.

Sharma, M., Kaur, V.I., Ansal, M.D., 2017. Physiological responses of freshwater ornamental fish koi carp, *cyprinus carpio* (L.) in Inland saline water: Growth and haematological changes. Indian J. Ecol. 44, 864–868.

Shephard, K.L., 1994. Functions for fish mucus. Rev. Fish Biol. Fish. 4, 401–429.

Shinn, A.P., Taylor, N., Wootten, R., 2006. Development of a management system for the control of *Ichthyophthirius multifiliis*. Trout News, Cefas 40, 21–25.

Shivappa, R.B., Christian, L.S., Noga, E.J., Law, J.M., Lewbart, G.A., 2015. Laboratory evaluation of safety and efficacy for Melafix (*Melaleuca cajuputi* extract). J. Exot. Pet Med. 24, 188–192.

Sicuro, B., Pastorino, P., Barbero, R., Barisone, S., Dellerba, D., Menconi, V., Righetti, M., De Vita, V., Prearo, M., 2020. Prevalence and antibiotic sensitivity of bacteria isolated from imported ornamental fish in Italy: A translocation of resistant strains? Prev. Vet. Med. 175.

Smith, K.F., Schmidt, V., Rosen, G.E., Amaral-Zettler, L., 2012. Microbial diversity and potential pathogens in ornamental fish aquarium water. PLoS One 7, 1–11.

Smith, P., Finnegan, W., Ngo, T., Kronvall, G. (2018). Influence of incubation temperature and time on the precision of MIC and disc diffusion antimicrobial susceptibility test data. Aquaculture 490, 19-24.

Sloman, K.A., Bouyoucos, I.A., Brooks, E.J., Sneddon, L.U., 2019. Ethical considerations in fish research. J. Fish Biol. 94(4), 556-577.

Soltanian, S., Gholamhosseini, A., Banaee, M., 2021. Effects of exposure to a therapeutic level of methylene blue on antioxidant capacity, haemato-immunological responses and resistance of goldfish, *Carassius auratus* to *Aeromonas hydrophila*. Aquac. Res. 52, 2640–2650.

Souza, A.C.P., Melo, K.M., de Azevedo, L.F.C., de Almada Vilhena, A.O., Nagamachi, C.Y., Pieczarka, J.C., 2020. Lethal and sublethal exposure of *Hemichromis bimaculatus* (Gill, 1862) to malachite green and possible implications for ornamental fish. Environ. Sci. Pollut. Res. 27, 33215–33225.

Souza, C.F., Baldissera, M.D., Guarda, N.S., Bollick, Y.S., Moresco, R.N., Brusque, I.C.M., Santos, R.C.V., Baldisserotto, B., 2017. *Melaleuca alternifolia* essential oil nanoparticles ameliorate the hepatic antioxidant/oxidant status of silver catfish experimentally infected with *Pseudomonas aeruginosa*. Microb. Pathog. 108, 61–65.

Sreedharan, K., Philip, R., Singh, I.S.B., 2012. Virulence potential and antibiotic susceptibility pattern of motile aeromonads associated with freshwater ornamental fish culture systems: A possible threat to public health. Brazilian J. Microbiol. 43, 754–765.

Stentiford, G.D., Bateman, I.J., Hinchliffe, S.J., Bass, D., Hartnell, R., Santos, E.M., Devlin, M.J., Feist, S.W., Taylor, N.G.H., Verner-Jeffreys, D.W., van Aerle, R., Peeler, E.J., Higman, W.A., Smith, L., Baines, R., Behringer, D.C., Katsiadaki, I., Froehlich, H.E., Tyler, C.R., 2020. Sustainable aquaculture through the One Health lens. Nat. Food 1, 468–474.

Stevens, C.H., Croft, D.P., Paull, G.C., Tyler, C.R., 2017. Stress and welfare in ornamental fishes: what can be learned from aquaculture? J. Fish Biol. 91, 409–428.

Strahilevitz, J., Jacoby, G.A., Hooper, D.C., Robicsek, A., 2009. Plasmid-mediated quinolone resistance: A multifaceted threat. Clin. Microbiol. Rev. 22, 664–689.

Sudova, E., Machova, J., Svobodova, Z., Vesely, T., 2007. Negative effects of malachite green and possibilities of its replacement in the treatment of fish eggs and fish: A review. Vet. Med. (Praha). 52, 527–539.

Suomalainen, L.R., Tiirola, M., Valtonen, E.T., 2005. Treatment of columnaris disease of rainbow trout: Low pH and salt as possible tools? Dis. Aquat. Organ. 65, 115–120.

Tampieri, M.P., Galuppi, R., Carelle, M.S., Macchioni, F., Cioni, P.L., Morelli, I., 2003. Effect of selected essential oils and pure compounds on *Saprolegnia parasitica*. Pharm. Biol. 41, 584–591.

Tavares-Dias, M., 2021. Toxic, physiological, histomorphological, growth performance and antiparasitic effects of copper sulphate in fish aquaculture. Aquaculture 535, 736350.

Taylor, N.G.H., Norman, R.A., Way, K., Peeler, E.J., 2011. Modelling the koi herpesvirus (KHV) epidemic highlights the importance of active surveillance within a national control policy. J. Appl. Ecol. 48, 348–355.

Taylor, N.G.H., Peeler, E.J., Denham, K.L., Crane, C.N., Thrush, M.A., Dixon, P.F., Stone, D.M., Way, K., Oidtmann, B.C., 2013. Spring viraemia of carp (SVC) in the UK: The road to freedom. Prev. Vet. Med. 111, 156–164.

Thilakaratne, I.D.S.I.P., Rajapaksha, G., Hewakopara, A., Rajapakse, R.P.V.J., Faizal, A.C.M., 2003. Parasitic infections in freshwater ornamental fish in Sri Lanka. Dis. Aquat. Organ. 54, 157–162.

Thoen, E., Evensen, Skaar, I., 2011. Pathogenicity of *Saprolegnia* spp. to Atlantic salmon, *Salmo salar* L., eggs. J. Fish Dis. 34, 601–608.

Tieman, D.M., Goodwin, A.E., 2001. Treatments for Ich Infestations in Channel Catfish Evaluated under Static and Flow-Through Water Conditions. N. Am. J. Aquac. 63, 293–299.

Tong, C., Hu, H., Chen, G., Li, Z., Li, A., Zhang, J., 2021. Disinfectant resistance in bacteria: Mechanisms, spread, and resolution strategies. Environ. Res. 195, 110897.

Tootoonchi, M., Gettys, L.A., 2019. Testing salt stress on aquatic plants: effect of salt source and substrate. Aquat. Ecol. 53, 325–334.

Trujillo-González, A., Becker, J.A., Vaughan, D.B., Hutson, K.S., 2018. Monogenean parasites infect ornamental fish imported to Australia. Parasitol. Res. 117, 995–1011.

Trushenski, J.T., Aardsma, M.P., Barry, K.J., Bowker, J.D., Jackson, C.J., Jakaitis, M., McClure, R.L., Rombenso, A.N., 2018. Oxytetracycline does not cause growth promotion in finfish. J. Anim. Sci. 96, 1667–1677.

Tukmechi, A., Hobbenaghi, R., Rahmati Holasoo, H., Morvaridi, A., 2009. Streptococcosis in a pet fish, *Astronotus ocellatus*: A case study. World Acad. Sci. Eng. Technol. 49, 14–15.

Udomkusonsri, P., Arthitvong, S., Klangkaew, N., Kusucharit, N., 2007. Pharmacokinetics of Enrofloxacin in Koi Carp (*Cyprinus carpio*) after Various Routes of Administration. Nat. Sci.) 41, 62–68.

Udomkusonsri, P., Noga, E.J., 2005. The acute ulceration response (AUR): A potentially widespread and serious cause of skin infection in fish. Aquaculture 246, 63–77.

van der Sar, A.M., Abdallah, A.M., Sparrius, M., Reinders, E., Vandenbroucke-Grauls, C.M.J.E., Bitter, W., 2004. *Mycobacterium marinum* strains can be divided into two distinct types based on genetic diversity and virulence. Infect. Immun. 72, 6306–6312.

Velappan, M., Munusamy, D., 2018. Pathological investigation of gill, intestine, liver and kidney of naturally infected Streptococcosis in ornamental fish, tiger oscar, *Astronotus ocellatus*. Res. J. Pharm. Technol. 11, 2549–2554.

Veterinary Medicines Directorate, 2016. Antibiotic resistance and the responsible use of antibiotics in animals; what work is the VMD doing?

Waller, P.J., Buchmann, K., 2001. Anthelmintic resistance and parasite control in commercial eel farms: Consequences for producers. Vet. Rec. 148, 783–784.

Wang, G.L., Xu, Y.J., Jin, S., Zhu, J.L., Yuan, S.P., 2007. Nocardiosis in snakehead, *Ophiocephalus argus* Cantor. Aquaculture 271, 54–60.

Weir, M., Rajić, A., Dutil, L., Cernicchiaro, N., Uhland, F.C., Mercier, B., Tuševljak, N., 2012. Zoonotic bacteria, antimicrobial use and antimicrobial resistance in ornamental fish: A systematic review of the existing research and survey of aquaculture-allied professionals. Epidemiol. Infect. 140, 192–206.

Whittington, R.J., Chong, R., 2007. Global trade in ornamental fish from an Australian perspective: The case for revised import risk analysis and management strategies. Prev. Vet. Med. 81, 92–116.

Yamazaki, Y., Hatai, K., Kubota, S., 1990. Studies on columnaris disease in guppy (*Poecilia reticulata*) II : Therapeutic effects of some drugs against *Flexibacter columnaris*. Bull. Nippon Vet. Zootech. Coll. 56–59.

Yanong, R.P., 2003. Use of antibiotics in ornamental fish aquaculture. EDIS 3, 1–7.

Zhang, W., Williams, A., Griffith, N., Gaskins, J., Bookstaver, P.B., 2020. Online availability of fish antibiotics and documented intent for self-medication. PLoS One 15, 1–12.

Zhang, X., Shang, B., Cheng, Y., Wang, G., Stojanovski, S., Li, W., 2022. Effects of different regimes of low temperature on egg hatching of *Dactylogyrus vastator* (Monogenea: Dactylogyridae). Exp. Parasitol. 240, 108333.

Zhou, L., Limbu, S.M.H., Qiao, F., Du, Z.Y., Zhang, M., 2018. Influence of Long-Term Feeding Antibiotics on the Gut Health of Zebrafish. Zebrafish 15, 340–348.

Ziarati, M., Zorriehzahra, M.J., Hassantabar, F., Mehrabi, Z., Dhawan, M., Sharun, K., Emran, T. Bin, Dhama, K., Chaicumpa, W., Shamsi, S., 2022. Zoonotic diseases of fish and their prevention and control. Vet. Q. 42, 95–118.

Table 1. Summary of the main diseases reported for freshwater fishes held as companion animals in home aquaria. For more detailed reviews which include gross signs of common diseases, see Cardoso et al. (2019, 2022).

Microorganism Category	**Disease**	**Symptoms**	**Examples of Susceptible Species**	**References**
Gram-negative bacteria	Columnaris disease (*Flavobacterium columnare*)	Yellowy white filamentous lesions predominantly affecting skin, gills and fins.	Mollies, platies, goldfish, koi, guppies.	Yamazaki et al., 1990; Decostere et al., 1998, 2002; Altinok, 2004; Roberts et al., 2009; Declercq et al., 2013.
	Edwardsiella piscida	Discoloured skin patches, external haemorrhages, indication of septicaemia, erratic swimming, exophthalmia.	Koi carp, goldfish, zebrafish.	Buján et al., 2018; Choe et al., 2017; McDermott & Palmeiro, 2020; Reichley et al., 2017; Zhang et al., 2021.
	Edwardsiella ictauluri	Enteric septicaemia.	Catfishes, considered emerging disease in ornamentals.	Hawke et al., 1981; Hawke et al., 2013; Kumar et al., 2019; McDermott & Palmeiro, 2020.
	Koi ulcerative disease (*Aeromonas salmoncidia*)	Cutaneous lesions which progressively erode the skin, exposing underlying musculature.	Koi, goldfish.	Elliott and Shotts, 1980; Gan et al., 2015.
	Motile aeromonad disease (*A. hydrophilia*, *A. veronii* biovar *veronii*, *A. caviae*).	Sloughing of scales, skin, fins, abdominal dropsy, exophthalmia, haemorrhage; in systemic cases haemorrhagic septicaemia.	Wide range of ornamentals.	Hossain et al., 2019c; Hossain & Heo, 2021; Jagoda et al., 2014; Sreedharan et al., 2012.

	Pseudomonas spp. infection.	Tail and fin rot, haemorrhage, and ulceration.	Wide range of ornamentals.	El-Hady and Samy, 2011; Fayed et al., 1997.
	Vibriosis (*Vibrio* spp.).	Ulceration, haemorrhage and haemorrhagic septicaemia.	Wide range of ornamentals.	Roberts et al., 2009.
Gram positive bacteria	Streptococcosis	Haemorrhages (particularly around the operculum, eye, and base of fins), exophthalmia, cloudy eyes, ulcerations, and erratic spiral swimming behaviour.	Cyprinids and cichlids such as red-tail black shark, rainbow shark, oscar, blue ram.	Lazado et al., 2018; Raissy et al., 2012; Tukmechi et al., 2009; Russo et al., 2006; Tukmechi et al., 2009; Velappan and Munusamy, 2018; Lazado et al., 2018.
Acid fast bacteria	Nocardiosis	Presents similarly to mycobacteriosis; distinguished by the branching, filamentous morphology of the bacteria.	Neon tetras, oscar, goldfish, and Chinese high-fin banded shark.	Conroy, 1964; Sheikhzadeh et al., 2020; Wang et al., 2007.
	Mycobacteriosis	Chronic (survival 4-8 weeks) and acute infections (survival 5-16 days). Ascites, lethargic behaviour, spinal defects, loss of appetite, scale loss, exophthalmia, emaciation, ulcerations and depigmentation.	Reported in over 150 species, including ornamentals.	Decostere et al., 2004; Puk and Guz, 2020; van der Sar et al., 2004; Gauthier and Rhodes, 2009; Puk and Guz, 2020; Wang et al., 2007.

Protozoan Parasites	Velvet disease (*Piscinoodinium* spp.)	In heavily infected fishes, a rusty-coloured velvet-like appearance. Mortality can occur due to extensive epithelial damage compromising osmoregulatory functions.	Wide range of ornamentals, typically tropical species.	Ferraz and Sommerville, 1998; Lieke et al., 2020.
	White spot disease (*Ichthyophthirius multifiliis*)	White raised spots covering most of body. Flashing, and general lethargic behaviour often seen. High mortality if not treated promptly.	Wide range of ornamentals.	Dickerson, 2011; Ekanem et al., 2004; Ezz EI Dien et al., 1998; Francis-floyd et al., 2016; Iqbal and Haroon, 2014; Matthews, 2005.
Metazoan Parasites	*Gyrodactylus* spp. (Skin fluke)	Affects the skin, gills and fins of the fish. Symptoms depend on infection site. Thickening of the fins/fin erosion, skin erosion, gill histopathological changes, excess mucus production all common.	Wide range of ornamentals.	Dewi et al., 2018; Mohamed et al., 2010; Mousavi et al., 2013; Thilakaratne et al., 2003; Trujillo-González et al., 2018; Yandi et al., 2017
	Dactylogyrus spp. (Gill fluke)	Chiefly affects the gills but also infects skin of the fish. Causes histopathological changes to gill	Largely cyprinid and poeciliid species such as barbs, koi, guppies, goldfish, and tetras.	Dewi et al., 2018; Mohammadi et al., 2012; Molokomme et al., 2023; Thilakaratne et al.,

		tissue and impaired respiratory function. Reduced growth, lethargy and gill flashing behaviours often seen.		2003; Trujillo-González et al., 2018; Yandi et al., 2017
	Camallanus spp. (nematode)	Subclinical in many cases. In heavily infected fish symptoms include poor body condition, abdominal swelling, lethargy, red worms protruding from vent, abnormal faeces and mortality.	Various ornamental species, particularly livebearers.	Ferreira et al., 2019; Kim et al., 2002; Levsen, 2001; Martins et al., 2007; Palmeiro and Roberts, 2012
	Capillaria spp. (nematode)	Similar symptoms to *Camallanus* however worms protruding from vent will be white.	Various ornamental species, particularly cichlids.	Adel et al., 2013; Dewi et al., 2018; Palmeiro and Roberts, 2012; Rahmati-Holasoo et al., 2023; Thilakaratne et al., 2003
Fungal-like diseases	Oomycetes (‘water moulds’ e.g. *Saprolegnia*, *Achyla*, and *Dictyuchus* spp.)	Cottony thread-like lesions on body surface. Often secondary infection of pre-existing lesions.	Wide range of ornamentals.	Gozlan et al., 2014; Howe and Stehly, 1998; Khoo, 2000; Noga, 2010; Udomkusonsri and Noga, 2005.

Table 2. Studies reporting antimicrobial resistance in bacteria isolated from ornamental fishes since 2010. Only studies containing data on n ≥ 20 isolates are reported. Antibiotics listed from least to most effective. Antibiotics with the same % resistant isolates are grouped together. MAR = Multiple antimicrobial resistance index = number of antibiotics resistant to/ total number of antibiotics tested. Where data were only represented graphically, numerical values were obtained using GetData Graph Digitizer ver. 2.26.0.20.

Study	**Bacterial spp.** **(n of isolates)**	**Geographical origin**	**Biological sample**	**Antibiotics tested and % of isolates resistant**	**MAR** **(min-max, mean)**
(Čížek et al., 2010)	*Aeromonas* spp. (n = 72)	Czech Republic, Koi farms	Koi carp *Cyprinus carpio koi*, gills, and skin swabs	Oxytetracycline (50%); Ciprofloxacin (25%); Trimethoprim (15%); Chloramphenicol, Florfenicol (7%)	-
(Dias et al., 2012)	*Aeromonas* spp., *A. aquariorum* (n = 43), *A. hydrophila* (n = 67), *A. veronii* (n = 94), *A. culicicola* (n = 16)	Portugal, ornamental fish importer	Various ornamental fish species, skin, and water samples	Carbenicillin (96%); Ampicillin (94%); Amoxicillin (95%); Erythromycin (88%); Tetracycline (80%); Ticarcillin (73%); Trimethoprim/sulfamethoxazole (36%); Cephalothin (32%); Kanamycin (31%); Gentamicin (28%); Cefoxitin (24%); Ticarcillin/clavulanic acid (22%); Tobramycin (19%); Ciprofloxacin (18%); Norfloxacin (16%); Amoxicillin/clavulanic acid (15%); Chloramphenicol (13%); Netilmicin (11%); Piperacillin (7%); Amikacin (6%); Ceftriaxone (5%); Ceftazidime, Cefoperazone (4%); Piperacillin/ clavulanic acid (3%); Imipenem (1%); Cefotaxime, Cefepime, Aztreonam (0%)	-

(Sreedharan et al., 2012)	*Aeromonas caviae* (n = 20)	India, goldfish farms	Water samples from goldfish *Crassius auratus*, culture systems	Norfloxacin, Ofloxacin, Pefloxacin, Sparfloxacin, Pipemidic acid, Nalidixic acid, Amoxicillin, Doxycycline HCl, Ampicillin, Colistin, Bacitracin, Vancomycin, Erythromycin, Oxytetracycline, Tetracycline Methicillin, Penicillin G, Cloxacillin, Ticarcillin, Oxacillin, Cephaloridine, Clindamycin, Lincomycin, Fusidic acid, Polymixin B (100%); Novobiocin (60%); Cephalothin, Oleandomycin, Spiramycin (40%); Piperacillin, Carbenicillin, Cephalexin, Cefazolin, Cephradine Cephadroxil, Chlortetracycline, Minocycline, Chloramphenicol, Rifampicin, Cefaclor, Cephoxitin, Cefamandole, Cefriaxone, Ceftazidime, Cefoperazone, Ceftizoxime, Imipenem, Amikacin, Gentamycin, Kanamycin, Neomycin, Netillin, Streptomycin, Tobramycin, Azithromycin, Tylosine, Clarithromycin, Nitrofurazone, Furazolidone, Furaxone, Trimethoprim, Sulfadiazine, Sulfafurazole, Sulfaphenzole, Ciprofloxacin, Nitrofurantoin, Enrofloxacin, Floxidine, Nitroxoline, Fosfomycin (0%)	0.243-0.457, -
	Aeromonas jandaei (n = 23)	India, goldfish farms	Water samples from goldfish *C. auratus*, culture systems	Norfloxacin, Ofloxacin, Pefloxacin, Sparfloxacin, Amoxicillin, Doxycycline HCl, Ampicillin, Bacitracin, Erythromycin, Oxytetracycline, Tetracycline Methicillin, Penicillin G, Cloxacillin, Ticarcillin, Cephaloridine, Clindamycin, Lincomycin, Fusidic acid, Polymixin B (100%); Colistin (74%); Oleandomycin (56.5%); Cephalexin, Cefazolin, Cephradine, Cephalothin, Cephoxitin (30.4%); Oxacillin (26.1%); Pipemidic acid, Nalidixic acid, Vancomycin (26%); Spiramycin, Piperacillin, Carbenicillin, Cephadroxil, Chlortetracycline, Minocycline, Chloramphenicol, Rifampicin, Cefaclor, Cefamandole, Cefriaxone, Ceftazidime, Cefoperazone, Ceftizoxime, Imipenem, Amikacin, Gentamycin, Kanamycin, Neomycin, Netillin, Streptomycin, Tobramycin, Azithromycin, Tylosine, Clarithromycin, Nitrofurazone, Furazolidone, Furaxone, Trimethoprim, Sulfadiazine, Sulfafurazole, Sulfaphenzole, Ciprofloxacin, Novobiocin, Nitrofurantoin, Enrofloxacin, Floxidine, Nitroxoline, Fosfomycin (0%)	0.243-0.457, -
(Rose et al., 2013)	Various spp. (n = 64)	USA, ornamental fish importer	Various ornamental fishes, kidneys	Tetracycline (77%); Trimethoprim/sulphamethoxazole (73%); Azithromycin (68%); Cefadroxil (65%); Ampicillin, Ciprofloxacin (58%); Gentamycin (50%); Kanamycin (35%); Cefotaxime (16%)	

(Jagoda et al., 2014)	*Aeromonas* spp., *A. veronii* (n = 34), *A. veronii* atypical (n = 7), *A. hydrophila* (n = 4), *A. caviae* (n = 3) *A. dhakensis* atypical (n = 2) *A. jandaei* (n = 1), *A. enteropelogenes* (n = 1)	Sri Lanka, commercial aquaria and breeding farms	Various septicaemic ornamental fishes, kidneys and liver	Amoxicillin (98.1%); Tetracycline (59.5%); Erythromycin (54.7%); Trimethoprim/sulphamethoxazole (26.4%); Nitrofurantoin (22.6%); Neomycin (9.4%); Chloramphenicol, Enrofloxacin (7.5%)	-
(Chung et al., 2017)	*Aeromonas veronii* (n = 30)	Korea, ornamental fish importer	Various ornamental fishes, organs sampled unknown	Ampicillin (96.7%); Tetracycline (80%); Piperacillin (73.3%); Sulfamethoxazole/trimethoprim (56.7%); Enrofloxacin (46.7%); Marbofloxacin (40%); Gentamicin (30%); Tobramycin (26.7%); Ceftiofur (20%); Imipenem (10%); Chloramphenicol (6.7%); Amikacin (3.3%); Amoxicillin/clavulanic acid, Cefpodoxime, Nitrofurantoin (0%)	-
(Hossain et al., 2018)	*Aeromonas* spp., *A. hydrophila* (n = 30), *A. veronii* (n = 32), and *A. punctata* (n = 3)	Korea, ornamental fish stores	Healthy goldfish *C.auratus*, whole body	Amoxicillin, Nalidixic acid, Levofloxacin, Amikacin (100%); Ampicillin (98.46%); Tetracycline (92.31%); Rifampicin (86.15%); Cephalothin (61.45%); Trimethoprim/sulfamethoxazole (44.62%); Doxycycline (26.15%); Gentamicin, Kanamycin (6.15%); Cefoxitin, Imipenem, Chloramphenicol (4.61%); Ciprofloxacin, Ofloxacin (1.54%); Ceftriaxone (0%)	-
(Hossain et al., 2019a)	*Aeromonas* spp., *A. veronii* biovar *veronii* (n = 26), *A. veronii* biovar *sobria* (n = 3), *A. hydrophila* (n = 8), *A. caviae* (n = 3), *A. enteropelogenes* (n = 2), and *A. dhakensis* (n = 1)	Korea, ornamental fish stores	Zebrafish *Danio rerio*, whole body	Amoxcillin, Nalidixic acid, Oxytetracycline (100%); Ampicillin (93.2%); Tetracycline (74.42%); Rifampicin (67.44%); Imipenem (65.15%); Trimethoprim/sulfamethoxazole (27.91%); Cephalothin (25.58%); Ciprofloxacin (6.98%); Chloramphenicol (4.65%); Nitrofurantoin (2.33%); Amikacin, Kanamycin, Cefotaxime (0%)	0.19-0.44, -

(Hossain et al., 2019b)	*Aeromonas* spp., *A. veronii* (n = 34), *A. dhakensis* (n = 10), *A. hydrophila* (n = 3), *A. caviae* (n = 3) and *A. enteropelogenes* (n = 2)	Korea, ornamental fish stores	Healthy guppy *Poecillia reticulata*, whole body	Amoxicillin, Nalidixic acid, Oxytetracycline (100%); Ampicillin (92.30%); Imipenem (71.15%); Cephalothin, Tetracycline (51.92%); Trimethoprim/sulfamethoxazole (50%); Gentamicin (21.15%); Kanamycin (13.46%); Nitrofurantoin (7.69%); Chloramphenicol (5.77%); Ciprofloxacin (5.76%); Cefotaxime (3.85%); Ceftriaxone (1.92%); Amikacin (0%)	0.28-0.67, -
(Hossain et al., 2019c)	*Aeromonas* spp., *A. hydrophila* (n = 30), *A. veronii* biovar *veronii* (n = 32), and *A. caviae* (n = 3).	Korea, ornamental fish stores	Healthy goldfish *C. auratus*, whole body	Amoxicillin, Nalidixic acid (100%); Ampicillin (98.46%); Tetracycline (92.31%); Rifampicin (90.77%); Cephalothin (66.15%); Trimethoprim/sulfamethoxazole (49.23%); Doxycycline (26.15%); Gentamicin, Kanamycin (6.15%); Cefoxitin, Imipenem, Chloramphenicol (4.62%); Ciprofloxacin (1.54%); Cefotaxime, Levofloxacin, Ofloxacin, Amikacin (0%)	0.22-0.56, 0.36
(Delalay et al., 2020)	Various spp. (Exact isolate number not reported, 1448 isolates used in entire study, n > 20 per antimicrobial)	Switzerland, various sources (private owners, fish stores etc.)	Various species of clinically ill ornamental fishes, liver spleen and kidney	Sulphonamide (67%); Oxolinic acid (44.6%); Erythromycin (44.1%); Oxytetracycline (41.5%); Tetracycline (36.9%); Cefepime (32.7%); Florfenicol (31.5%); Sulphonamide/trimethoprim (27.2%); Chloramphenicol (18.3%); Gentamicin (14.1%); Amikacin (12.2%); Norfloxacin (10.8%)	-
			Clinically ill koi *C. carpio koi*, liver spleen and kidney	Sulphonamide (74.7%); Oxolinic acid (73.7%); Oxytetracycline (63.8%); Tetracycline (60.5%); Erythromycin (50.5%); Florfenicol (42.2%); Chloramphenicol (41.3%); Norfloxacin (36.1%); Sulphonamide/trimethoprim (34.6%) Amikacin (34.3%); Cefepime (24.7%); Gentamicin (24%)	-
			Clinically ill goldfish *C. auratus*, liver spleen and kidney	Sulphonamide (64%); Oxolinic acid (48%); Oxytetracycline (45.5%); Tetracycline (39.1%); Erythromycin (32%); Sulphonamide/trimethoprim (29.2%); Norfloxacin (19%); Chloramphenicol (16%); Gentamicin (8%)	-

(Haenen et al., 2020)	*Aeromonas* spp. (n = 59)	Global ornamental fish consignments imported into the Netherlands	Various tropical ornamental fishes, skin, and internal organs	Tetracycline (85%); Flumequine (53%); Trimethoprim/sulfamethoxazole (30%); Neomycin (34%); Nitrofurantoin (17%); Florfenicol (9%)	-
(Preena et al., 2020a)	Various spp. (n = 25)	India, ornamental fish farm	Clinically infected koi, gills, liver, and spleen. Data also provided on goldfish but isolates n < 20	Furazolidone (72.72%); Bacitracin (45.5%); Trimethoprim, Cephalothin, Cefalexin (45.45%); Vancomycin, Rifampicin, Azithromycin, Streptomycin, Ampicillin (36.36%); Nalidixic acid (30%); Oxytetracycline, Perfloxacin (27.3%); Nitrofurantoin, Sulphadiazine, Erythromycin, Tobramycin, Gentamycin, Cefoxitin, Cefazolin, Cefoperazone (18.2%); Aztreonam (18%); Amikacin, Colistin, Enrofloxacin, Chloramphenicol, Co-trimoxazole, Imipenem, Amoxyclav (9.1%); Piperacillin, Ceftazidime (9%) Cefepime, Cefixime/clavulanic acid, Cefotaxime, Cefotaxime/clavulanic acid, Ceftriaxone, Cefuroxime, Amoxicillin, Doripenem, Meropenem, Piperacillin/tazobactam, Kanamycin, Ciprofloxacin, Levofloxacin, Norfloxacin, Polymyxin-B (0%)	0-0.34, -
(Saengsitthisak et al., 2020)	*Aeromonas* spp., *A. sorbria* (n = 41), *A. hydrophilia* (n = 18), and *A. caviae* (n = 5)	Thailand, ornamental fish shops	Clinically diseased goldfish *C. auratus*, koi *C. carpio koi* and red swordtail *Xiphophorus hellerii*, liver and spleen	Amoxicillin (93.75%); Oxytetracycline (79.69%); Erythromycin (75%); Sulfamethoxazole/trimethoprim (46.88%); Ciprofloxacin (40.63%); Enrofloxacin, Norfloxacin (25%); Gentamicin (17.19%); Amikacin (12.5%); Nitrofurantoin (7.81%); Chloramphenicol (6.25%); Ceftazidime (0%)	-
(Sicuro et al., 2020)	Various spp. (exact isolate number not reported, estimated n ≥ 91)	Italy, ornamental fish importer	Various ornamental fishes, kidneys	Lincomycin (97.1%); Erythromycin (86.9%); Ampicillin (86.5%); Oxytetracycline (80.7%); Tetracycline (78.9%); Oxolinic acid (76.1%); Amoxicillin (74.3%); Amoxicillin/clavulanic acid (60%); Enrofloxacin (57.8%); Neomycin (54.9%); Furazolidone (53.2%); Sulfamethoxazole/trimethoprim (48.4%); Spectinomycin (47.8%); Flumequine (42.7%); Gentamicin (41.2%); Chloramphenicol (34.7%); Florfenicol (21.9%)	-

(Dhanapala et al., 2021)	*Aeromonas* spp., *A. veronii* (n = 122), *A. hydrophilia* (n = 15), *A. caviae* (n = 8), *A. jandaei* (n = 7), *A. dhakensis* (n = 6), *A. sobria* (n = 1), *A. media* (n = 1), and *A. popoffii* (n = 1)	Sri Lanka, commercial aquaria and breeding farms	Water samples, skin and mucous samples from various healthy ornamental fishes, kidney samples from various moribund ornamental fishes	Amoxicillin (92.5%); Enrofloxacin (67.1%); Nalidixic acid (63.4%); Erythromycin (26.1%); Tetracycline (23.6%); Imipenem (18%); Gentamicin, Trimethoprim/sulfamethoxazole (16.8%); Nitrofurantoin (8.1%); Doxycycline (5%); Chloramphenicol (3.7%); Rifampicin (2.5%); Ceftazidime (1.2%)	0.08-0.86, -
(Preena et al., 2021)	Various spp. from Enterobacteriaceae group (n = 84)	India, ornamental fish farms	Moribund goldfish *C. auratus*, gills, liver, kidney, and spleen	Ampicillin, Vancomycin (100%); Amoxicillin, Bacitracin (84.6%); Cephalothin, Oxytetracycline (76.9%); Cefazolin, Azithromycin, Erythromycin, Nitrofurantoin, Rifampicin (69.2%); Aztreonam, Nalidixic acid, Colistin (61.5%); Sulphadiazine (53.8%); Cefalexin, Cefuroxime, Cefoperazone, Gentamycin, Streptomycin, Polymyxin-B (46.1%); Amikacin, Amoxyclav, Piperacillin, Piperacillin/tazobactam, Cefixime/clavulanic acid , Cefotaxime, Cefotaxime/clavulanic acid, Cefepime, Carbapenem, Tobramycin, Furazolidone (38.4%); Cefoxitin (30.7%); Meropenem, Levofloxacin, Norfloxacin, Co-trimoxazole, Chloramphenicol (23%); Doripenem, Imipenem, Enrofloxacin, Trimethoprim (15.3%); Ceftriaxone (7%); Ciprofloxacin, Perfloxacin (0%)	0.21-0.85, 0.45
(Guz and Puk, 2022)	Rapidly growing *Mycobacterium* spp. (n = 50)	Poland	Diseased ornamental fishes	Rifampicin, Isoniazid (100%); Doxycycline (78%); Ciprofloxacin (44%); Sulfamethoxazole, Tobramycin (40%); Clarithromycin (16%); Amikacin (6%); Kanamycin (2%);	-
	Slowly growing *Mycobacterium* spp. (n = 49)			Isoniazid (97.96%); Rifampicin (93.88%); Ciprofloxacin (16.33%); Tobramycin (10.2%); Doxycycline (6.12%); Clarithromycin (2.04%); Amikacin, Kanamycin, Sulfamethoxazole (0%)	-

(Au-Yeung et al., 2022)	*Aeromonas* spp. (n = 22-38) Data also presented on *Psuedomonas* spp. however resistance prevalence only assessed for *Aeromonas* spp.	Hong Kong, ornamental fish shops	Carriage water containing either zebrafish (*D. rerio*), southern platys (*Xiphophorus maculatus*), or koi (*Cyprinus rubrofuscus*)	Tetracycline (97.4%); Oxalinic acid (95%); Oxytetracycline (94.9%); Enrofloxacin (70%); Doxycycline (55%)	-

Table 3. Systematic search of common "over the counter" products for treating bacterial, fungal, and parasitic diseases in ornamental fishes. The list of products was taken from 'BSAVA (2020) Small Animal Formulary Part B: Exotic Pets Appendix III; Proprietary fish medicine vendors' with additional products added if identified, although will not be exhaustive on a global scale. Products were included if they were applicable to treating pet fishes destined for freshwater aquaria. Searches were performed in Web of Science (WoS) and Scopus databases in October 2022, October 2023 and June 2024. Where products had generic names which generated excessive hits the brand name was specified prior to the product using the Boolean operators "".

Brand	Product	Active ingredients	Target pathogen	Search term	Hits WoS	Hits Scopus	Unique Hits	# Relevant	Notes on Relevance
API (USA)	Melafix	Cajeput oil	Bacteria	Melafix	3	3	3	2	Related to product
	Pimafix	West Indian Bay oil	Fungi	Pimafix	2	2	2	1	Related to product
	White Spot Cure	Malachite green, Polyvinylpyrrolidone	Protozoa	"API" White Spot Cure	0	0	0	0	
Aquarium Münster (Germany)	Argumor	Diflubenzuron	Flukes and crustaceans	Argumor	0	0	0	0	
	Dactymor forte	Cyromazine	Flukes	Dactymor forte	0	0	0	0	
	Dessamor	Copper sulphate,Ethacridine lactate, Methylthioninium chloride, Acriflavine	Fungi	Dessamor	0	0	0	0	
	Ektomor	Sodium perborate, Magnesium peroxide	Fungi, bacteria, and protozoa	Ektomor	0	0	0	0	
	Faunamor	Methylthioninium chloride, Malachite green, Methylrosaniline, Acriflavine	Protozoa	Faunamor	0	0	0	0	
	Medimor	Ethacridine lactate, Methylthioninium chloride, Methyl orange, Acriflavine	Fungi, bacteria, and protozoa	Medimor	0	0	0	0	
	Odimor	Copper sulphate, Malachite green	Fungi, bacteria, and protozoa	Odimor	0	0	0	0	
	Protomor	Malachite green, Ethacridine lactate, Methylthioninium chloride, Gentian violet	Protozoa	Protomor	0	1	1	0	Unrelated to product
	Virumor	Potassium peroxymonosulphate	Fungi and bacteria	Virumor	0	0	0	0	

Blue planet (Australia)	Aquari cycline	Tetracycline hydrochloride	Bacteria	Aquari cycline	0	0	0	0	
	Fluke & tapeworm tablet	Praziquantel	Flukes and cestodes	Fluke and tapeworm tablet	1	1	1	0	Unrelated to product
	Multi cure	Malachite green, Methylene blue, Acriflavine	Protozoa and Fungi	"Blue planet" Multi cure	0	0	0	0	
	Para cide	Trichlorfon	Crustaceans and Flukes	"Blue Planet" Para cide	0	0	0	0	
	Tri sulfa	Sulfadizine, Sulfadimidine, Sulfamerazine	Bacteria, Fungi, and protozoa	Tri sulfa	9	9	14	0	Unrelated to product
eSHa Labs (Netherlands)	eSHA 2000	Ethacridine lactate, Copper sulphate, Proflavine hemisulphate	Fungi, bacteria, and protozoa	eSHa 2000	10	0	10	0	Unrelated to product
	eSHa alx	Lufenuron	Crustaceans	eSHa alx	0	0	0	0	
	eSHa EXIT	Ethacridine lactate, Malachite green, Methylene blue	Protozoa	eSHa EXIT	1	0	1	0	Unrelated to product
	eSHa gdex	Praziquantel	Flukes and cestodes	eSHa gdex	0	0	0	0	
	eSHa Hexamita	Copper sulphate, Ethacridine lactate, Acriflavine, Methylene blue	Fungus, bacteria and protozoa	eSHa Hexamita	0	0	0	0	
	eSHa-ndx	Levamisole hydrochloride, Sodium metabisulphite, Methyl parahydroxybenzoate	Nematodes	eSHa-ndx	0	0	0	0	
Interpet (UK)	Anti Crustacean Parasite Plus	Sodium chlorite	Crustaceans	Anti Crustacean Parasite Plus	0	0	0	0	
	Anti Fungus & Finrot Plus	2-phenoxyethanol	Fungi and bacteria	Anti fungus and Finrot Plus	0	0	0	0	
	Anti Internal Bacteria Plus	Formaldehyde, Bronopol, Benzalkonium chloride	Bacteria	"Interpet" Anti Internal Bacteria	0	0	0	0	
	Anti Parasite, Slime & Velvet Plus	Formaldehyde, Benzalkonium chloride, Copper EDTA, Quinine bisulphate	Protozoa and Flukes	Anti Parasite, Slime & Velvet Plus	0	0	0	0	

	Anti White Spot Plus	Formaldehyde, Malachite green	Protozoa	"Interpet" Anti White Spot Plus	0	0	0	0	
	Swimbladder Treatment Plus	Formaldehyde, Bronopol, Benzalkonium chloride	Bacteria	Swimbladder Treatment Plus	0	0	0	0	
JBL (Germany)	Aradol Plus	Diflubenzuron	Crustaceans	Aradol Plus	0	0	0	0	
	Ektol bac Plus	Benzalkonium chloride, Methylene blue, Polyvinylpyrrolidone iodine	Bacteria	Ektol bac Plus	0	0	0	0	
	Ektol fluid Plus	Methylene blue, Benzalkonium chloride	Bacteria	Ektol fluid Plus	0	0	0	0	
	Fungol Plus	Malachite green oxalate, Ethacridine lactate, Povidone iodine	Fungi	Fungol Plus	0	0	0	0	
	Furanol Plus	Nifurpirinol	Bacteria	Furanol Plus	1	1	2	0	Unrelated to product
	Gyrodol Plus	Praziquantel	Flukes and cestodes	Gyrodol Plus	0	0	0	0	
	Nedol Plus	Benzimidazole	Worms	Neodol Plus	1	1	1	0	Unrelated to product
	Oodinol Plus	Copper sulphate, Methylthionimium chloride	Protozoa	Oodinol Plus	0	0	0	0	
	Punktol Plus	Malachite green oxalate, Methylthionimium chloride	Protozoa	Punktol Plus	0	0	0	0	
	Spirohexol Plus	2-amino-5-nitrothiazole	Protozoa	Spirohexol Plus	0	0	0	0	
King British (UK)	Bacteria control	Formaldehyde, Magnesium sulphate, Sodium chloride, Allantoin	Bacteria	"King British" Bacterial Control	0	0	0	0	
	Disease Clear	Silver proteinate	Fungi and bacteria	"King British" Disease Clear	0	0	0	0	
	Fin Rot & Fungus Control	2-phenoxyethanol	Fungi and bacteria	"King British" Fin rot and fungus control	0	0	0	0	

	Original Formula WS3	Malachite green, Acriflavin, Quinine sulphate	Protozoa	Original Formula WS3	1	1	1	0	Unrelated to product
	White Spot Control	Malachite green, Acriflavin, Quinine sulphate	Protozoa	"King British" White Spot Control	0	0	0	0	
NT Labs (UK)	Aquarium Anti White-spot & Fungus	Formaldehyde,Malachite green	Fungi and protozoa	Aquarium Anti White-spot and Fungus	0	0	0	0	
	Aquarium Anti-Fluke & Wormer	Flubendazole	Flukes and worms	Aquarium Anti-Fluke and Wormer	0	0	0	0	
	Aquarium Anti-Internal Bacteria	Chloramine T	Bacteria	Aquarium Anti-Internal Bacteria	0	0	0	0	
	Aquarium Anti-Parasite	Copper sulphate, Formaldehyde	Protozoa	Aquarium Anti-Parasite	1	1	1	0	Unrelated to product
	Aquarium Anti-Ulcer & Finrot	Acriflavin, Aminoacridine hydrochloride, Formaldehyde	Bacteria	Aquarium Anti-Ulcer and Finrot	0	0	0	0	
	Aquarium Disease Solve	Acriflavine, Methylene blue	Pathogens	Aquarium Disease Solve	3	1	3	0	Unrelated to product
	Aquarium Swimbladder Treatment	Acriflavine, Aminoacridine hydrochloride	Bacteria	Aquarium Swimbladder Treatment	4	1	4	0	Unrelated to product
Oase (Germany)	AntiArgulus	Diflubenzuron	Crustaceans	AntiArgulus	0	0	0	0	
	AntiFungus	Ethic lactate mono, Methyl chloride, Acrid monocular	Fungi	"Oase" AntiFungus	0	0	0	0	
	AntiParasite	Methythionium chloride, Malachite green oxalate, Methylrosabilinium chloride, Acriflavine monochloride	Protozoa	"Oase" AntiParasite	0	0	0	0	
Seachem (USA)	Cupramine	Copper sulphate	Protozoa	Cupramine	3	9	11	1*	*Only relevant result is for marine ornamentals
	Focus	Nitrofurantoin	Fungi and bacteria	"Seachem" Focus	0	0	0	0	

	Kanaplex	Kanamycin sulphate	Fungi and bacteria	Kanaplex	0	0	0	0	
	Metroplex	Metronidazole	Bacteria and protozoa	"Seachem" Metroplex	0	0	0	0	
	Neoplex	Neomycin sulphate	Bacteria	Neoplex	5	18	19	0	Unrelated to product
	Paraguard	Aldehyde, Malachite green, Polymers	Fungi, bacteria and protozoa	Paraguard	4	13	13	0	Unrelated to product
	Polyguard	Sulfathiazole, Malachite green, Nitrofurantoin, Nitrofural, Quinacrine dihydrochloride	Fungi, bacteria and protozoa	Polyguard	10	19	29	0	Unrelated to product
	Sulfaplex	Sulfathiazole	Fungi, bacteria and protozoa	Sulfaplex	0	0	0	0	
Sera (Germany)	Argulol	Denatonium benzoate, Emamectin benzoate	Crustaceans	Argulol	0	0	0	0	
	Bakto Tabs	Nifurpirinol	Bacteria	Bakto Tabs	0	0	0	0	
	baktopur	Acriflavine, Methylene blue, Phenyl glycol	Bacteria	baktopur	0	0	0	0	
	costapurF	Malachite green, Formaldehyde	Fungi and protozoa	costapurF	0	0	0	0	
	ectopur	Sodium perborate, Sodium borate, Sodium chloride	Fungi, bacteria and protozoa	ectopur	0	0	0	0	
	Flagellol	Nitro thiazolylazane, Ascorbic acid, Menadione sodium bisulphite	Protozoa	Flagellol	0	0	0	0	
	mycopur	Acriflavine chloride, Copper sulphate/chloride	Fungi and Flukes	mycopur	0	0	0	0	
	Nematol	Emamectin benzoate	Nematodes	"Sera" Nematol	17	0	17	0	Unrelated to product
	Phyto med Baktazid	Thyme oil	Bacteria	Phyto med Baktazid	0	0	0	0	
	Phyto med Catappa	Catappa extract	Fungi, bacteria and external parasites	Phyto med Catappa	1	0	1	0	Unrelated to product
	Phyto med Mycozid	Thyme oil	Fungi	Phyto med Mycozid	0	0	0	0	
	Phyto med Protazid	Quinine hydrochloride	Protozoa	Phyto med Protozid	0	0	0	0	
	Phyto med Tremazid	Peppermint oil	Flukes	Phyto med Tremazid	0	0	0	0	

	Protazol	Phenyl methylium hydroxide	Fungi and protozoa	Protazol	0	0	0	0	
	Tremazol	Praziquantel	Flukes and cestodes	Tremazol	0	0	0	0	
Tetra (UK)	ContraIck Plus	Methylthioninium chloride, Malachite green oxalate, Methylrosanilinium chloride, Acriflavine chloride	Protozoa	ContraIck Plus	0	0	0	0	
	Fungistop Plus	Ethacridine lactate, Methylthionium chloride, Acriflavine chloride		Fungistop Plus	0	0	0	0	
	Fungus Guard Tablets	Nitrofurazone, Potassium dichromate	Fungi	Fungus Guard Tablets	0	0	0	0	
	GeneralTonic Plus	Ethacridine lactate, Acriflavine, Methylene blue, 9-Aminoacridine hydrochloride	Bacteria and protozoa	GeneralTonic Plus	0	0	0	0	
	Goldmed	Formaldehyde, Malachite green oxalate	Fungi, bacteria, and protozoa	Goldmed	2	2	3	0	Unrelated to product
	Ick Guard Tablets	Victoria green, Acriflavine	Protozoa	Ick Guard Tablets	0	0	0	0	
	Lifeguard Tablets	1-chloro-2,2,5,5-tetramethyl-4-imidazolidinone	Fungi, bacteria, and protozoa	Lifeguard Tablets	2	2	2	0	Unrelated to product
VetArk (UK)	Chlormaine T	Sodium N-chloro-para-toluenesulfonamide	Bacteria, protozoa, and flukes	Chloramine T	1	0	1	0	Unrelated to product
	Fluke-Solve	Praziquantel	Flukes	Fluke-Solve	0	0	0	0	
	Fluke-Solve Plus	Emamectin benzoate, Nitroscanate, Praziquantel	Flukes	Fluke-Solve Plus	0	0	0	0	
	Lice-Solve	Emamectin benzoate	Crustaceans	Lice-Solve	1	1	1	1	Related to product
Waterlife (UK)	Medizin	Formaldehyde, Malachite green, Methylene blue, Alkyl-dimethyl-benzyl-ammonium chloride	Fungi and protozoa	"Waterlife" Medizin	0	0	0	0	
	Myxazin	Benzalkonium chloride, Formaldehyde, Malachite green, Acriflavine	Bacteria	Myxazin	0	0	0	0	
	Nova+	Tea tree extract	Fungi, bacteria and protozoa	"Waterlife" Nova+	0	0	0	0	
	Octozin	Dimetridazole	Protozoa	Octozin	0	0	0	0	

	Protozin	Malachite green, Formaldehyde, Copper sulphate	Fungi and protozoa	Protozin	1	2	2	0	Unrelated to product
	Sterazin	Formaldehyde, Malachite green	Flukes	Sterazin	0	0	0	0	