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RESEARCH PAPER

A review of polymer-based water conditioners for reduction of handling-related injury

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Abstract Fish are coated with an external layer of protective mucus. This layer serves as the primary barrier against infection or injury, reduces friction, and plays a role in ionic and osmotic regulation. However, the mucus layer is easily disturbed when fish are netted, handled, transported, stressed, or subjected to adverse water conditions. Water additives containing polyvinylpyrrolidone (PVP) or proprietary polymers have been used to prevent the deleterious effects of mucus layer disturbances in the commercial tropical fish industry, aquaculture, and for other fisheries management purposes. This paper reviews research on the effectiveness of water conditioners, and examines the contents and uses of a wide variety of commercially available water conditioners. Water conditioners containing polymers may reduce external damage to fish held in containers during scientific experimentation, including surgical implantation of electronic tags. However, there is a need to empirically test the effectiveness of water conditioners at preventing damage to and promoting healing of the mucus layer. A research agenda is provided to advance the science related to the use of water conditions to improve the condition of fish during handling and tagging.

Keywords Fish · Mucus · Scales · Polymer

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Introduction

Fish are commonly handled by researchers and aquaculturists for a variety of reasons (e.g., external examination, recording of length and weight, transport, surgical implantation of transmitters). Handled fish are at risk of acquiring injuries to their epidermal layer from contact with capture gear (i.e., nets, hooks) and sampling equipment (i.e., measuring boards, surgery table). These injuries can be latent (e.g., mucus loss) or visually apparent (e.g., scale loss) and can result in sub-lethal and lethal consequences for the fish. Some researchers utilize commercially available water conditioners (e.g., PolyAqua, Stress Coat) to aid in the protection of the epidermal layer of fish, and to promote healing if injury does occur. However, the effectiveness of these products and any negative effects they may have on fish have not been thoroughly investigated. The goal of this review is to examine the contents, uses, and effectiveness of polymer-based water conditioners and provide recommendations for future research.

The epidermal layer of fishes is abundant with goblet, Malpighian, and other secretory cells that serve as the primary biological interface between teleost fish and their environment by producing a layer of protective mucus (Shephard 1994; Ottesen and Olafsen 1997). Mucus consists mainly of water, along with high molecular weight, gel-forming macromolecules that are predominated by glycoproteins known as mucins (Shephard 1994). The mucus layer serves as the primary barrier against infection (Pickering 1974; Pickering and Macey 1977; Ingram 1980; Alexander and Ingram 1992; Nagashima et al. 2001), protects against injury (Pickering and Richards 1980), reduces friction (Rosen and Cornford 1971; Pickering 1974), and plays a role in ionic and osmotic regulation (Handy et al. 1989; Shephard 1994).

The mucus layer is easily disturbed when fish are netted, handled, transported, stressed, or subjected to adverse water conditions such as high particulates (Roberts and Bullock 1980; Buermann et al. 1997) and contaminants (Muniz and Leivestad 1980; Eddy and Fraser 1982). Disturbances to the mucus layer may alter the ionic and osmoregulatory abilities of fish while also making them vulnerable to scale loss, skin abrasions, and a variety of bacterial, fungal, and parasitic diseases (Wedemeyer 1996). These disturbances can be particularly harmful to juvenile salmonids undergoing the parr–smolt transformation because they can alter the developing hypoosmoregulatory ability that pre-adapts the fish to life in seawater (Wedemeyer 1996). The smoltification process requires large amounts of energy reserves and is stressful to fish (Specker 1982; Virtanen 1987), as indicated by outbreaks of disease upon seawater entry (Stoskopf 1993). For example, Bouck and Smith (1979) reported coho salmon smolts *Oncorhynchus kisutch* experienced 75% mortality when exposed to salt water following experimentally induced mucus and scale loss, compared to 0% mortality for smolts exposed to freshwater following injury. Although the mucus layer can be regenerated relatively quickly, the compensatory energy required to do so may compromise the survival of fish as they enter seawater (Wedemeyer 1996).

For these reasons, it is desirable to prevent or minimize the effects of any disturbance to the mucus layer that may occur during the netting, handling (including surgical tag implantation), and transporting of fish. The tropical fish industry has successfully used water additives containing polyvinylpyrrolidone (PVP) or proprietary polymers to prevent the deleterious effects of mucus layer disturbances that can occur during the transportation of aquarium fish (Wedemeyer 1996). When abrasions and scale loss do occur, these polymers temporarily bond to proteins on the exposed tissue, forming a protective coating that is displaced as healing proceeds and the mucus layer is regenerated (Wedemeyer 1996). These polymer formulations are being used increasingly by the aquaculture industry and state and federal conservation hatcheries as a water additive for transporting juvenile salmonids and other non-food fish (Wedemeyer 1996; Harmon 2009).

Research related to water conditioners

Relatively few studies have been published in peer-reviewed fisheries journals regarding the usefulness of these polymer formulations (summarized in Table 1). Some of the studies conducted have shown potential benefits of water additives containing synthetic polymers for minimizing handling and transport mortality. Much of this research was conducted using black bass *Micropterus* species that were held in live wells containing water conditioners or other additives. For example, survival of angled largemouth bass *Micropterus salmoides* held for 3–9 h in water that contained an unspecified commercially available water conditioner was significantly higher than survival of angled fish held in unconditioned water (Plumb et al. 1988). However, there was no significant difference in survival between angled fish that were released immediately and those that were held in the conditioned water. Gilliland (2003) explored the effectiveness of different live-well operating procedures in reducing mortality of black bass and found that the live-well additives significantly improved the survival of tournament catches in Oklahoma.

Several studies have indicated that water conditioners were used effectively in aquaculture facilities. For example, mortality was reduced by 23–43% when Polyaqua, a commercially available water conditioner, was added to holding tanks while adult steelhead *Oncorhynchus mykiss* were examined repeatedly for

Table 1 Summary of studies examining the effectiveness of polymer-based water conditioners

Species	*n*	Total length (mm)	Water conditioner used	Application	Measure	Source
Largemouth bass	85	215–535	1 mg of unspecified commercially available per 75 L of water	Live well conditions in live release angling tournaments	Survival up to 6 weeks after capture	Plumb et al. 1988
Smallmouth bass	3	NA	0.5% Catch‘n’Release Formula	Live well conditions in live release angling tournaments	Cardiac recover times	Cooke et al. 2002
Adult Chinook salmon	NA	NA	100 ppm Polyaqua	Transport of adult salmonids	Prespawn mortality	Wedemeyer 1996
Adult steelhead	NA	NA	100 ppm Polyaqua	Transport of adult salmonids	Prespawn mortality	Wedemeyer 1996
Adult steelhead	NA	NA	100 ppm Polyaqua	Holding of adult salmonids	Prespawn mortality	Wedemeyer 1996
Delta smelt	900	47–51*	NovAqua in 8% NaCl	Holding and transport post-capture	Mortality within 72 h post-capture	Swanson et al. 1996

NA Not available

* Mean fork length

spawning ripeness over a 3-month period (Wedemeyer 1996). A concentration of 100 ppm Polyaqua used during transport significantly reduced the prespawning mortality of adult fall Chinook salmon *Oncorhynchus tshawytscha* and steelhead caused by the freshwater fungus *Saprolegnia* (Wedemeyer 1996). Addition of NovAqua, another commercially available conditioner, to transport water increased survival of delta smelt *Hypomesus transpacificus* captured using a seine net by about 27% over that of the control (Swanson et al. 1996). The improved survival was attributed to the polymers, which may have reduced physiological stress responses, such as osmotic imbalances (Swanson et al. 1996).

Although most studies have found water conditioners to be effective at reducing stress and increasing survival of handled or transported fish, Cooke et al. (2002) found increased cardiac recovery times for smallmouth bass *Micropterus dolomieu* held in live wells conditioned with 0.5% Catch-and-Release Formula that was gradually flushed with lake water compared to fish held in live wells that were flushed with only lake water, suggesting that conditioners may be detrimental to fish recovery. However, this study was limited by sample size ($n = 3$). Prolonged recovery following stress (e.g., handling and surgery) could potentially increase the likelihood of mortality or behavioral alterations. One of the challenges associated with using water conditioners is that many are proprietary with claims of effectiveness that often are not validated (Cooke et al. 2002).

Use of water conditioners

Despite the lack of research related to the use of water conditioners, they appear throughout the literature in studies involving the transport and holding of fish. Water conditioners are generally not used for the transport of food-fish, since they are not approved by the FDA. However, water conditioners, such as Propolyaqua, Polyaqua, Novaqua, and Start Right, have been used in the transportation of a variety of species including rainbow trout, channel catfish, largemouth bass, walleye, bluegill, brown trout and splittail *Pogonichthys macrolepidotus* (Taylor and Kynard 1985; Carmichael and Tomasso 1988; Swanson et al. 1996; Helfrich et al. 2001; Danley et al. 2002; Weber et al. 2002; Beeman and Maule 2006; Floyd et al. 2007; Kline and Bonar 2009). Commercially available water conditioners are also often added to live wells and/or recovery tanks during and after angling tournaments, such as those for largemouth bass (Plumb et al. 1988; Meals and Miranda 1994), as well as in recovery tanks after surgical implantation of transmitters (Stress Coat, Godinho and Kynard 1993; Stress Coat, Richardson-Heft et al. 2000; Polyaqua, Gaines and Martin 2004). Polymer-based water conditioners have also been used to soak or coat the surgical pad (Stress Coat, Hockersmith et al. 2000) or work surface (Stress Coat, Peterson and Barfoot 2003; Polyaqua, Mueller et al. 2006). In addition, water conditioners such as Polyaqua and Vidalife have been added to anesthetic solutions used in tagging procedures (Ficke and Myrick 2009; Brown et al. 2010, Seitz et al. 2010).

Contents of water conditioners

Many water conditioners are commercially available, but some are formulated only to dechlorinate water and/or bind heavy metals. These conditioners use dechlorinating agents such as sodium thiosulfate and ascorbic acid, chelating (metal binding) agents such as ethylenedianinetetra acetic acid (EDTA), and buffering agents such as tris (hydroxymethyl) aminomethane that restore acid–base balance. Water additives that form a protective "slime layer" will contain a polymer (often PVP or carboxymethyl cellulose [CMC]) or colloid (Table 2). Some additives contain aloe extract from leaves of the *Aloe vera* plant. Manufacturers of these products claim that the *Aloe vera* extract promotes healing of damaged tissue. One potential drawback to water additives that contain *Aloe vera* extract or CMC is the addition of organic waste load that can reduce the water quality and oxygen levels in a closed system. This may not be an issue, depending on the density of fish, length of time fish are held, and oxygen content of the water. However, the effects of these substances on gill tissue are unclear. Taiwo et al. (2005) tested the survival and behavior of tilapia (*Oreochromis niloticus*) exposed to different concentrations of aqueous extract of *A. vera* for up to 96 h. One hundred percent of tilapia exposed to 50 ppm *A. vera* died within the duration of the experiment. Fish used in this experiment exhibited severe depigmentation and destruction of organs (including gills). The evidence of the toxic effects of *A. vera* on fish solidifies the need to empirically test water conditioners, and their chemical components, for potential negative effects on fish.

Table 2 Partial list of commercially available water additives that claim to provide mucus layer protection

Product	Manufacturer	Mucus layer protector	Mucus layer protection	Dechlorination	Binds heavy metals
Ultimate	Aqua Science	Tertiary polymer system	X	X	X
Stress Coat	Aquarium Pharmaceuticals, Inc. (API)	Nontoxic polymer	X	X	X
Minnow Holding Formula	Better Bait	Unknown	X	X	X
Kent Pro Tech Coat	Freshwater	PVP[a]	X	X	X
Aquaplus	Hagen Nutrafin	PVP and CMC[b]	X	X	X
Start Right	Jungle Laboratories (Jungle)	PVP	X	X	X
NovAqua	Kordon	Synthetic colloid	X	X	X
NovAqua+	Kordon	Proprietary	X	X	X
PolyAqua	Kordon	Synthetic polymer	X		X
BIO-Coat	Marineland	PVP	X		
U2 Pro Formula	The Oxygenator	Unknown	X	X	X
Prime	Seachem	Proprietary	X	X	X
StressGuard	Seachem	Non-amine–based polymer	X		
Vidalife	Syndel Laboratories Ltd.	PVP	X		X
Aquasafe	Tetra Aqua	PVP	X	X	X
Haloex	Waterlife	Proprietary	X	X	X

[a] *PVP* polyvinylpyrrolidone

[b] *CMC* carboxymethyl cellulose

Research needs

This review highlights the need for empirical studies to examine the effects of water conditioners on fish. Comparative studies should be conducted to investigate the differences in currently available and employed water conditioners such as those highlighted in this review (e.g., Polyaqua, Stress Coat). These comparative studies should explore the effectiveness of multiple water conditioners for reducing mucus loss and infection for fish, as well as examining the sublethal and lethal effects these water conditioners may have on fish.

Although polymer-based water conditioners are commonly used during fish surgery, no known studies have been conducted to examine their effectiveness in this function. The application of a polymer-based water conditioner to the transport water, anesthetic solution, and surgery table may prevent the harmful effects of mucus layer disturbances that can occur during the tagging process. However, research is needed to compare the effectiveness of multiple water conditioners used in various applications during the surgery procedure.

Because disturbance to the mucus layer of fish is often latent, the detection and quantitative measurement of mucus loss can be difficult. However, recent studies have found fluorescein, a non-toxic dye, to be an effective means for identifying latent epithelial damage on fish (Noga and Udomkusronsi 2002; Davis and Ottmar 2006; Dauble et al. 2007; Colotelo et al. 2009). Fluorescein could be used to quantify the initial amount of experimentally-inflicted injury on fish and to document the healing process of fish treated with different water conditioners. It could also be used to determine the effectiveness of polymer-based water conditioners to prevent damage to the mucus layer.

Conclusion

Water conditioners containing polymers may reduce external damage to fish held in containers during scientific experimentation, including surgical implantation of transmitters. However, there is a need to empirically test the effectiveness of water conditioners at preventing damage to and promoting healing of the mucus layer. It is unadvisable to use water additives that contain *Aloe vera* extract or CMC in closed holding systems due to the potential for these additional organic wastes to reduce water quality and oxygen levels. However, these organic materials likely do not have a negative effect on water quality or oxygen levels in open, flow-through holding or transport systems. Because no studies have directly compared multiple water conditioners, additional research is needed to determine which additive best protects the mucus layer of fish under different conditions. Additionally, to understand all the potential applications and the extent of polymer-based water conditioner use in fisheries applications, the authors encourage others to report their use of water conditioners, including the specific brand and concentration used.

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