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Effective Science Journalism: Theory and Practice

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Abstract

Science communication is the interface between the general public and the scientific community. When science communication is effective, it allows the public to understand and engage with scientific discussions. If science communication is not effective, it isolates the public from the scientific community. Unfortunately, there are many cases where science communication is not effective. It is not easy to communicate complex scientific topics in a way that the general public can understand. It is even harder to do so in a way that does not misconstrue science. This project investigates the current literature on effective science journalism practice and theory. I use the tools and knowledge I gain from the literature review to write an article for *Western Confluence* magazine. I then discuss the process and highlight specific examples of where I incorporate what I learned into the article. Through this project, I improve my own understanding and practice of science journalism, and I synthesize the current practices that are deemed effective by scholars and practitioners within the field of science journalism.

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Chapter 1

Introduction to Science Journalism

Imagine a vast canyon with steep, rugged walls. At the bottom of the canyon, there is a massive, jumbled pile of papers. One group stands on the east side of the canyon, talking in groups, exchanging papers, and periodically throwing papers off the edge of the canyon into the depths below. Another group of people watches from the west side of the canyon. Some of those on the west side are decked out in full climbing gear, and frantically rappel down the steep cliffs to reach the canyon floor below. At the bottom of the canyon, the climbers sift through piles upon piles of papers, throwing some aside, and selecting others to take back to the top of the canyon. As they climb back to the top, more papers flutter down into the canyon from the east, waiting to be retrieved.

The people on the east side of the canyon are scientists, tossing important and valuable peer-reviewed scientific articles off the edge of the cliff into the canyon—a maze of academic journals. The people on the west side of the canyon are the general public, and the climbers, retrieving information out of the canyon and delivering it to the public, are journalists and science writers.

This canyon metaphor paints a caricature of the current state of science communication. Science journalists are not only tasked with determining what is important to communicate to the public but also with translating scientific jargon and science writing formats into something that the public can understand. The traditional science format of abstract, introduction, methods, results and discussion are useful within the scientific community, because these structures help the scientists strive towards objectivity, avoid bias, and provide greater efficiency in the process.

But for the general public, this format is not as engaging as other forms of writing such as narrative journalism. Much of the time, the tasks of translating jargon and weaving a narrative to communicate science are conducted without the help of scientists.

Science journalists and communicators must be able to understand the scientific language and culture, pick out information that is relevant to the general public, and translate science into everyday language so that the public can understand the science. On top of these monumental challenges, science communicators must be able to captivate the interest of their audience. In this way, science communicators serve the public by gathering and providing information that is relevant and accessible to them. When done properly, science communicators bridge the gap between scientists and the public. Unfortunately, few journalists are effective science communicators, and they often fail to successfully inform the general public (Bryant, 2003; Sevian & Gonsalves, 2008; Treise & Weigold, 2002).

Importance and Definition of Science Communication

There are many reasons why the general public needs to understand science. The report "Science and the Public: A review of Science Communication and Public Attitudes of Science in Britain" released by the Office of Science and Technology and the Wellcome Trust in 2001 found that "public perceptions of science play an increasingly important role in developing policy" (p. 13). The National Environmental Policy Act of 1969 mandated that the American public should be incorporated into decision-making, and that science be incorporated into policy decisions. In order for the public to participate in the political and ethical debates surrounding science, the public needs to understand more science (Treise & Weigold, 2002). As public perceptions contribute more to policy development, there is also a greater need for effective science communication to make sure that the public has access to high quality information. At the same time, the amount of background scientific knowledge needed to participate in political discussions and decisions has increased exponentially in the last century, compounding the need for effective science communication (Baram-Tsabari & Osborne, 2015).

While science communication can help the public understand, become aware of, and participate in political and ethical debates surrounding science (Baron, 2010; Durant, Evans, & Thomas, 1989; Lewenstein, 2015; Stocklmayer, Gore, & Bryant, 2001), there are more reasons why science communication is important for the general public today. One reason is that science affects Americans' everyday lives. Technology, a product of the advancement of science, makes our lives easier by making transportation more efficient, communication more widespread, and medicine more advanced (Durant et al., 1989; Lewenstein, 2015; Stocklmayer, Gore, & Bryant, 2001). Science communication helps keep people up to date on the latest advancements so that people can understand how science is affecting their lives today and in the future.

For many people, science also has an intrinsic value, and it is simply interesting to learn about (Durant et al., 1989). A survey of British attitudes towards science found that "three-quarters of the British population are 'amazed' by the achievements of science," and only one fifth are not interested in science (Office of Science and Technology and the Wellcome Trust, 2001, p. 5). Between the intrinsic value, the ethical and political implications, and the day-to-day impacts of science, it is clear that communicating science is an important endeavor, important enough that it should be defined by success (Treise & Weigold, 2002).

In order to begin to understand what success means in this field, first science communication needs to be defined. Bryant (2003) defines science communication as "the processes by which the scientific culture and its knowledge become incorporated into the common culture" (p. 357). "Scientific culture" refers to what scientists do on a day-to-day basis, including how they conduct research, the language that they use, and their values and norms (Bryant, 2003; Stocklmayer et al., 2001). “Common culture” refers to the culture of the target audience, which includes the audience’s language, norms, and values (Bryant, 2003). Finally, the process of the scientific culture becoming incorporated into the common culture refers to the work of the communicator. A successful science communicator bridges the two cultures of science and the public so that the two cultures can communicate with and understand one another.

My Interest and Role in Science Communication

My interest in science communication stems from my passion for biology and environmental science education. My undergraduate degree is in biology, with a focus in molecular ecology. While working towards my degree, I conducted research on the population genetics of softshell turtles. With my advisor, Dr. Steven Freedberg, I wrote a scientific paper on the research, and it has been accepted for publication through the *Journal of Herpetology* (Reinertsen et al., 2015). In other words, I have participated in throwing a scientific paper into the metaphorical canyon of science communication.

Since graduating college, I have migrated towards the other side of the canyon—the science communicator side. Currently, I am pursuing a Master’s of Science in Natural Science Education and Environment and Natural Resources. I completed my first year of graduate school in the Teton Science Schools’ Graduate Program, where I learned how to teach science outdoors to a wide range of age groups. While attending the graduate program, I also wrote a blog for the program’s Facebook page. The blog covered the science content that I was learning from faculty and teaching to my students, as well as my experience living in Grand Teton National Park. This year, I am finishing my graduate degree at the University of Wyoming where I work as an editorial fellow for *Western Confluence* magazine. Working for *Western Confluence* brings together my passion for biology and education through science journalism.

Working for *Western Confluence* is the inspiration for this project, and its goals and audience are the context that guides this project. *Western Confluence* magazine communicates complex natural resource management issues in the western United States to the general public. The magazine searches for solutions to natural resource management issues, and it presents these solutions to the public in a way that a person without an advanced degree can understand. The goal of each article is to help readers 1) understand the complexities of important natural resource management issues, 2) understand new research findings relevant to decision making or management, and 3) make well-informed decisions and work toward management solutions by providing the readers with information. Ultimately, awareness and understanding of the issues will increase the ability of the reader to make decisions related to resource management issues. The target audience of the magazine includes scientists, managers of natural resources (ranchers, irrigators, etc.), teachers, and users of natural resources in the west. For *Western Confluence*, science communication is successful if it meets these three goals with the target audience for each article.

Each issue of *Western Confluence* focuses on one topic within natural resource management in the western United States. The winter 2014 issue investigates rangeland ecology and agriculture; the summer 2014 issue covers forest management; the winter 2015 issue reports on water management; and the summer 2015 issue examines wildlife habitat, nutrition, and migration. I wrote two articles that appeared in the winter 2015 issue of the magazine. Lacking training or education in journalism or communications, I relied on writing skills honed through my liberal arts education, as well as guidance and edits from Emilene Ostlind, the editor of

Western Confluence. For the summer 2015 issue of the magazine, I wrote an article on the introduction of lake trout in Yellowstone Lake. The literature review conducted for this project equipped me with the knowledge and tools of effective journalism identified by the scholars and practitioners within the field in order to improve my own journalism practice, and it is a resource for other science journalists who are seeking to improve their practice. The primary goal of the project is to apply the effective practices of science journalism identified in the literature review into the article for *Western Confluence* to improve my own practice.

The first section of the literature review describes the shift in the theory of science communication, and the second section reviews effective science journalism practice. Following the literature review, the discussion describes how I incorporated what I learned from the literature review into the article for *Western Confluence*. The first section of the discussion details the writing process, including how I collect information, conduct interviews, and write the article. The second section contains the article on lake trout introduction with comments inserted throughout, and shows how I incorporate what I learn from the literature review into the article. Finally, the third section includes reflections on the writing process, as well as a reflection on how the entire process of using a literature review to inform the article works. The article (a draft version from April 30th, 2015) is located in Appendix A. Editing of the article continues up until the publication. Following the publication of the article in *Western Confluence* in June of 2015, I will replace the draft with the final version of the article as it appears in the magazine.

Chapter 2

Literature Review

For the purposes of this literature review, I used peer-reviewed literature that can be found in the field of science communication. Research in education, psychology, and sociology can, and will, contribute to the field of science communication; however, for the scope of this paper, I did not seek out articles outside of the field of science communication. Each of these topics: "how psychology research can inform science journalism," "how educational theory can inform science journalism," or "how sociology can inform science journalism" could be an individual thesis project. I wanted to inform my science journalism practice with the effective methods identified by scholars and professionals within the field, because I wanted my work to be relevant and representative of current science journalism practice.

Finding peer-reviewed journal articles on the theory of science communication proved to be fairly easy and informative. I started my search for literature by looking for articles on the theory of science communication by using search words and phrases including "effective science communication," "effective science journalism," and "theory of science communication." The articles I found described the field of science communication's history, and included research on the effectiveness of science communication in the past. These articles make up the first section of the literature review, "Theory of Science Communication."

It proved much more difficult to find peer-reviewed journal articles on the effective practice of science journalism, because there is limited research on the actual practice of science journalism (Baram-Tsabari & Lewenstein, 2013). In order to find articles on the practice of science journalism, I started by looking at resources cited by articles I had already found. I also added key words to my searches such as “narrative,” “relevance,” and “clarity” to find more articles.

The lack of research in the field may be due to the difficulty of studying science journalism practices. For a controlled scientific study, a particular article would have to be written in two (or more) ways, and then presented to an audience to test which way is more effective. This approach is problematic, because it is difficult to isolate and manipulate a single component of an article. It is also difficult, because very few people are willing to invest the energy to write an article multiple ways. Case studies and rhetorical analysis have been used as an alternative to comparative scientific studies to validate different journalism practices (Alsop, 1999); however, these case studies have limited power to identify exactly what components of science communication lead to effective science journalism.

Although there is little research on effective practices of science journalism, there are many books written on the topic. Accomplished science journalists have written numerous how-to books on practices of effective science journalism. These practices are deemed effective, because they have been used in articles that appear in the most prestigious news outlets, and some practices have also been supported by the limited amount of research that is present in the field (Treise & Weigold, 2002). The second section of the literature review, “Practice of Effective Science Journalism,” includes how-to books, along with the limited peer-reviewed articles that exist on effective practices in science journalism.

Theory of Science Communication

In the last 25 years, there has been a major shift in how scholars think about science communication (Wiederhold, 2011). Prior to the 1990s, science communication was guided by the principles of the deficit model, which assumes public ignorance of science and scientific concepts (Bryant, 2003). The deficit model presents science communication as a one-way street, in which information is communicated from scientists to the public (Miller, 2001). Under this model, the people that make up the general public are largely viewed as empty glasses waiting to be filled with scientific knowledge, and the primary problem to be addressed by science communication is a lack of knowledge, or a deficit (Miller, 2001). Baram-Tsabari and Osborne (2015) describe how the deficit model "rests on the assumption that the more scientific information the public has, the more its decisions will support or agree with the scientific consensus, and the more sympathy the public would have toward science" (p. 137). This view puts scientists in an ivory tower, where their knowledge is the truth, and the public must learn and assimilate these truths into their daily lives.

Research suggests that the assumptions inherent in the deficit model do not reflect what is really going on in science communication (Miller, 2001). One assumption the deficit model relies on is that greater scientific knowledge leads to greater trust and sympathy towards science (Baram-Tsabari & Osborne, 2015, p. 137). This assumption is challenged by studies that have found that "variance in public attitudes on controversial socio-scientific issues is better explained by values, emotions, ideology, social identity, and trust in scientific and other institutions than by scientific knowledge" (Baram-Tsabari & Osborne, 2015). The assumption that more scientific knowledge will lead to greater support of science does not hold up against this research.

A second assumption of the deficit model is the assumed ignorance of the public. Supporters of the deficit model look to studies of scientific literacy to support this assumption. These studies test the public's knowledge of scientific facts, which are selected by scientists as representative of the knowledge needed to be scientifically literate (Paisley, 1998). Studies investigating scientific literacy largely paint a poor picture of public knowledge of science (Miller, 2001; Paisley, 1998; Turney, 1996).

In a National Science Foundation survey conducted in 2001, “half the respondents did not know that the earliest humans lived long after dinosaurs, that it takes the Earth 1 year to go around the sun, that electrons are smaller than atoms and that antibiotics do not kill viruses,” which, when combined with the rest of the responses from the survey, many scholars took to mean that the general public is scientifically illiterate (Bryant, 2003, p. 358). In landmark studies of British and American public understanding of science conducted in 1988, public *interest* in science was high, whereas public *understanding* of science was low (Durant et al., 1989). Public understanding of science included knowledge of science and the scientific process. On the topic of scientific process, “less than 14% of respondents made any mention either of theory construction and hypothesis testing, or of the experimental method” (Durant et al., 1989, p. 12). When this same survey was given to scientists at workshops, the results were not significantly different: “there is no significant difference between the overall scores of the scientists and the public” (Bryant, 2003, p. 358).

What do the results of these surveys mean? Bryant (2003) believes that the surveys show that “the knowledge of each person is uneven and idiosyncratic,” even among the scientific community, and that the inability of the public to answer factual questions correctly is not a proper measure of scientific literacy or public understanding of science (p. 358). Does it really matter if a person does not know that the Earth goes around the Sun once a year? Will lack of this knowledge affect their daily decisions? Many of the facts tested by this survey, and others like it, are not relevant to people’s lives (Bryant, 2003).

The deficit model and the surveys described rely on a definition of science literacy that Paisley (1998) labels "science content literacy." In science content literacy, scientists create a list of facts that they believe the public should know, and literacy is based on how well the public knows these facts; unfortunately, scientists do not agree on the facts that the public should know (Paisley, 1998). Further, whether knowledge of a set of facts counts for literacy is up for debate (Bryant, 2003). A more relevant science literacy, and one that science journalism has adopted today, is the "How Science Works" literacy, in which the goal is "a society that (a) is aware of how and why the scientific enterprise works and of its own role in that activity, and (b) feels more comfortable than it presently does with science and technology" (Shamos, 1995 p. 219). In this definition of science literacy, public awareness of science is emphasized more than public understanding of science. Public awareness of science is "a set of positive attitudes toward science (and technology) that are evidenced by a series of skills and behavioral intentions" (Burns, O'Connor, & Stocklmayer, 2003, p. 186). The goal of the "How Science Works" literacy is to have a public that is actively engaged with debates around scientific issues, and that understands the nature of science, the scientific processes, and practices in which scientists engage, as well as the facts and information related to the topic. The information that people learn is primarily important in relation to what the people are able to do with that information. Scientists are no more important in this paradigm than the public, and information is exchanged between groups instead of being defined by a one-way communication system.

The field of science communication dropped the deficit model in favor of the contextual model, which operates under the "How Science Works" literacy, in the mid 1990s; however, the contextual model has roots in studies by sociologists and historians of science from the 1970s. These sociologists and historians:

Began to question the idea that science is "created" in one sphere and then disseminated in another sphere, with distortion being an inevitable accompaniment of the dissemination. Instead, researchers began to talk about "expository science," emphasizing the way in which scientific information is shaped by the various audiences to which it can be addressed. At its core, this new tradition argues that scientific knowledge does not exist in any abstract form, but takes on shape and meaning only when it is expressed in specific contexts and addressed to specific audiences. (Lewenstein, 1995, p. 407-408)

This "new tradition" takes into account how information is always contextualized, and different audiences have different contextual frameworks (Lewenstein, 1995). Furthermore, the different forms of communication are not arranged in hierarchical order. One form of communication is not more valid or true than another form, and every form is connected in a circle or web of communication (Lewenstein, 1995). The 'new tradition' put forth in the 1970s is at the core of the contextual model adopted by science communication in the 1990s; different audiences have unique contexts, and these contexts influence how new information is learned.

The public presented by the contextual model is much more complex than the public presented by the deficit model. Under the contextual model, the public is not one unit; instead, the public is segmented into different communities, which have different interests and understand science on different levels and in different ways (Alsop, 1999; Jenkins, 1994; Turney, 1996). Each segment of the public has "intellectual baggage" that is used to contextualize new scientific information (Bryant, 2003, p. 357). This "intellectual baggage" is what Baram-Tsabari and Osborne (2015) refer to as "culturally relevant prior knowledge" (p. 138). Other authors refer to it as local knowledge (Burns et al., 2003; Gross, 1994; Miller, 2001), or "expertise about society and everyday life" (Turney, 1996, p. 4). This local knowledge influences understanding of science and whether or not the science is incorporated into a person's knowledge (Jenkins, 1994; Turney, 1996). This local knowledge plays a key role in public awareness and understanding of science. Information is not simply transferred from one person to another, as the deficit model would argue. When a person learns new information, that new information is contextualized within existing frameworks, or local knowledge, and new knowledge is created (Bryant, 2003). This new knowledge will be referred to as public understanding, as defined by the contextual model, which is drastically different than the public understanding defined by the deficit model, which is "the science which the public should know" (Jenkins, 1994, p. 602).

Public understanding in the contextual model is not viewed as less valid or less pure than scientific knowledge; both scientific knowledge and public understanding are authentic ways of knowing and creating knowledge (Gross, 1994; Miller, 2001; Turney, 1996). Interest and enjoyment play a crucial role in motivating the public to learn science (Burns et al., 2003). Unless science communication is able to communicate why the public should care about science, then the public will not be motivated to learn the information (Wiederhold, 2011). The contextual model leads to a "bottom up" approach to science communication, in which science communicators must start with what interests people, or what is relevant to people, instead of starting with what people *should* know, and presenting that information (Turney, 1996). On the other hand, if there is something the audience should know, then it is the job of the journalist to find ways to make the information interesting.

The contextual model defines a new goal for science communication: instead of transferring information to an ignorant public, "the goal of all science education or science communication should be to foster critical engagement rather than blind devotion" (Baram-

Tsabari & Osborne, 2015, p. 138). This new goal has far-reaching consequences. The contextual model empowers the public to determine ethical, social and political implications of science (Baram-Tsabari & Osborne, 2015; Gross 1994). Turney (1996) asserts that scientists will still play a significant role in scientific debates, but citizens that can understand science and how science works should keep scientists in check. The deficit model does not allow for the public to engage with science on ethical, social, or political terms, because it assumes an ignorant public. Under the contextual model, the public is a crucial component of making science meaningful, even if the public does not possess enough information to be considered scientifically literate (Office of Science and Technology & the Wellcome Trust, 2001; Turney, 1996).

Scientists, as well as the public, are viewed differently under the contextual model: "The focus has shifted to the deficits of the *scientists* in communicating with the public, with public engagement the perceived way to rebuild public trust and achieve a social consensus on controversial scientific issues" (Wiederhold, 2011, p. 629). To communicate effectively, scientists, just like science journalists, need to seek to understand how the public views science, and how science could affect society and public opinion (Bryant, 2003; Turney, 1996).

Ultimately, the conceptual model calls for "full, frank, and publicly inclusive dialogue, discussion, and debate about science and its implications for individuals and society" (Miller, 2001, p. 119). The general public is no longer viewed as a passive receptacle for scientific information. The public needs to be engaged with relevant information that can be used in everyday life. The role of the science communicator is to make science relevant and interesting, and to facilitate dialogue between scientists and the public. In essence,

> Good reporting can enhance the public's ability to evaluate science policy issues and the individual's ability to make rational personal choices; poor reporting can

> mislead and disempower a public that is increasingly affected by science and technology and by decisions determined by technical expertise. (Nelkin, 1995, p. 2-3)

The role of the science communicator is to empower the public by providing the public with relevant, interesting information that matters.

Practice of Effective Science Communication

The shift from the deficit model to the contextual model in the theory of science communication has directly impacted what is deemed as effective practice of science communication. The contextual model opens the door to starting with the audience, instead of starting with science. In this model, scientific knowledge is not viewed as holding more value than local knowledge; instead, each knowledge system is equally valued. By recognizing the audience's contextual frameworks, as well as their local knowledge, science writers take the first step towards presenting information in a relevant and interesting way. For each article, it is crucial to start with the audience, and to find ways to contextualize the information to make it relevant and interesting for the audience.

Effective science journalism is no longer defined solely by accurate reporting—the job of the science journalist is much more complex. The science journalist must report science accurately, while also engaging the reader and making direct connections to why the topic is relevant and interesting to the reader. Interest and relevance can be seen as the keys that science journalists use to unlock the contextual frameworks of the audience. By using frames that the audience already applies when interpreting the subject matter, the author allows the reader to relate to and process the information. In this way, science is presented within a context that allows the reader to understand and incorporate the information into his or her own existing knowledge.

The following section of the literature review investigates what makes effective science journalism. The main topics include developing clarity, relevance, interest, and accuracy in science journalism. As the contextual model points out, it is crucial to make science relevant and interesting. Furthermore, clarity and accuracy are key components of effective writing. I select these topics because they are the recurrent themes in the literature, and they also provide scaffolding to be able to discuss a wide variety of information that I gathered through the literature review.

Clarity. Science can be incredibly complex and difficult for the general public to understand. If science writing is also complex and difficult to understand, then science communicators can throw out any hope of communicating science. Clarity is crucial for effective science communication (Blum, 2006; Finkbeiner, 2006; Giles, 2002; Sevian & Gonsalves, 2008; Spinks, 2001; Stocklmayer et al., 2001). Through clear writing, it is easier for the audience to understand complex science (Sevian & Gonsalves, 2008).

Sentence structure is crucial to achieving clarity (Finkbeiner, 2006; Knudson, 2006; Spinks, 2001). The vocabulary in a sentence must comprise everyday language, or be at the level of the audience (Baron, 2010). Jargon, or words that are used within an expert community to convey large, complex ideas, are not appropriate in science communication (Spinks, 2001), and can in fact compete with the main message that the journalist is trying to communicate (Baron, 2010). Jargon should only be used (and defined clearly) if it is incredibly important to conveying the information, or the word is so frequently used that it would save time to explain; even if the word fits one or both of these criteria, there should only be one or two jargon words in an article (Baron, 2010).

Along with selecting simple words, verb choice can increase clarity (Knudson, 2006). Effective science writers use active verbs (Dunwoody, 2006; Giles, 2002). For example: "this sentence was written by Charlie Reinertsen," (passive voice) should be replaced with "Charlie Reinertsen wrote this sentence" (active voice).

Sentence length also affects clarity. Clear sentences are short (Baron, 2010). If a concept can be explained in fewer words, then it should be (Spinks, 2001). Any non-crucial word or phrase, such as "very," "there are," "it is," and "it," as well as excess "the's," can be deleted, and adverbs should not be used excessively (Finkbeiner, 2006). Not only do short sentences increase clarity but they also are more memorable (Wilkes, 2006), which helps the audience understand the message better (Baron, 2010).

Although concise sentences increase clarity, it is important that an article presents all of the information an audience needs to understand a concept. In the words of Guyer (2006), the "reader can learn anything she needs to know as long as the writer writes what the reader needs to know when she needs to know it. Make no leaps of knowledge or faith" (p. 30). In this way, science writing is a balance between "maximizing simplicity and impact" while "minimizing inaccuracy" (Spinks, 2001, p. 165). Spinks (2001) recommends that an author enlists a non-scientist and a scientist well versed on the subject to read the article before publishing. The non-scientist's job is to check for simplicity, and the scientist's job is to check for accuracy (Spinks, 2001). If both the non-scientist and the expert scientist are satisfied, then there is a proper balance. If the non-scientist is overwhelmed and the scientist is satisfied, there may be non-crucial information that can be removed to increase clarity (Dunwoody, 2006).

One way to make sure all of the crucial pieces of information are in place is to follow the AB/BC rule described by Finkbeiner (2006). The AB/BC rule is to start every sentence with the last word of the previous sentence. For example: "The cutthroat trout is an *anadromous freshwater fish*. An *anadromous freshwater fish* migrates from fresh water lakes upstream to spawn." The "AB/BC" rule ensures that the writer is proceeding step-by-step, without any pieces missing from the explanation. This rule can also be applied to paragraph structure with the transition sentence tying together one paragraph to the next (Finkbeiner, 2006).

Outside of sentence structure, there are tools that can be used to clearly communicate science. Metaphors and analogies are two of these tools (Baron, 2010; Dunwoody, 2006; Shreeve, 2006); however, each has the potential to cause as much damage as good (Strauss, 2009). A metaphor is "a figure of speech in which a word or phrase literally denoting one kind of object or idea is used in place of another to suggest a likeness or analogy between them (Merriam-Webster Dictionary). An analogy is a "resemblance in some particulars between things otherwise unlike" (Merriam-Webster Dictionary). Analogies and metaphors can take a concept that is unknown by the audience (the item being explained) and put it into context using something that is widely known by the audience. For example, "this literature review is a tool box for science journalists" is an example of an analogy that tries to explain the content and purpose of this literature review (what I want the audience to understand) in terms of a toolbox (a familiar concept). The inherent danger in analogies and metaphors is that they have the potential to create misconceptions by oversimplifying or misconstruing scientific concepts (Strauss, 2009); however, if analogies and metaphors are used properly, they can provide clarity to difficult concepts (Baron, 2010; Dunwoody, 2006; Shreeve, 2006). Unfortunately, there is little agreement on how to craft an effective metaphor. As Strauss (2009) claims, "ultimately there is science and there is metaphor, but as far as I can tell, there is no science to metaphor" (p. 165). It is up to the judgment of the writer to decide if the risk of misconceptions or oversimplification is worth the clarity that may result from the use of a metaphor.

Sometimes, instead of using a metaphor, specific examples or anecdotes can work to clarify a concept (Baron, 2010). Almost more important than examples are non-examples. Instead of simply explaining what something is, explaining what something is not will bring greater clarity to the subject (Dunwoody, 2006). For example, if trying to explain stream ecology, instead of simply describing what a degraded river looks like ("the banks are undercut, the channel is shallow and wide"), describe a healthy river as well ("there are riffles and pools, with vegetation covering the banks and providing structure, and the channel is narrow and deep"). Providing a mental image of what something is, as well as what something is not, helps a reader define a concept.

In science writing, statistics and data are nearly unavoidable. Reporting statistics or data is a potential roadblock for readers (Baron, 2010). Baron (2010) presents useful guidelines for reporting statistics and data. First, numbers should be "usable, memorable, and still faithful to the data" (Baron, 2010, p. 110). To accomplish this, Baron (2010) suggests authors sum up and simplify the math; use frequencies instead of probabilities; compare and contrast; and explain significance versus magnitude. An example of summing up and simplifying would be to report an average instead of the values reported from multiple days or years. Reframing probabilities in terms of frequencies (e.g. 1 in 1 billion people) makes it easier for the audience to understand the data (Baron, 2010). Comparing a number gives the number context; for example, the Empire State building is just 4% of the height of Mt. Everest. Along with comparing and contrasting, Baron (2010) suggests reporting data in the most powerful terms. A stronger way of comparing the Empire State building to Everest would be to say: Mt. Everest is 29,029 feet, which is the equivalent of over 23 Empire State buildings stacked end to end.

Finally, explaining significance versus magnitude is crucial, because in general, audiences do not know what statistical significance means (Baron, 2010). Magnitude refers to the size of the difference in the data, whereas statistical significance refers to the chance that the difference in the data can be attributed to chance alone. In this way, it is possible to have a statistically significant difference that has a very small magnitude.

Relevance and Interest. The shift from the deficit model to the contextual model allowed science communicators to recognize that audiences are varied, and they are not simple vessels waiting to be filled with information. In fact, different audiences have different interests and values, which influence what information is assimilated and what information is avoided (Nisbet & Mooney, 2007). The shift from the deficit model to the contextual model thus has major implications for the practice of science journalism; instead of simply choosing what information the public *should* know based on what the scientific community decides, science communicators must ask: what does the audience *want* or *need* to know? This question highlights perhaps the most important task of the science communicator: making information relevant and interesting to the audience (Baron, 2010).

As Baron (2010) explains, “If you begin by thinking about *their* [the audience’s] values, expectations, and interests, you can translate your information in a way that resonates instead of just dousing them with what’s on your mind” (p. 106). One of the most effective ways to make information relevant is to frame the information (Nisbet & Mooney, 2007). Nisbet defines frames in his paper “The ethics of framing science” (2009):

> Frames are the conceptual term for interpretative storylines that communicate what is at stake in a science-related debate and why the issue matters…. Framing research offers a rich explanation for how various actors in society define science-related issues in politically strategic ways, how journalists from various beats selectively cover these issues, and how diverse publics differentially perceive, understand, and participate in these debates…. Frames help simplify complex issues by lending greater weight to certain considerations and arguments over others, translating why an issue might be a problem, who or what might be responsible, and what should be done. (p. 51)

Framing, as described by Nisbet, is how people relate to information. It is the context in which the information becomes relevant to the audience. Baron (2010) defines framing more succinctly: "'frames' are interpretative storylines that communicate what is at stake in a societal debate and why the issue matters" (p. 112). Frames are successful when they fit existing "values, knowledge, and attitudes" of an audience (Nisbet, 2009, p.1767).

Framing is *not* a means to manipulate information; it is a way to contextualize and make sense of information (Nisbet & Sheufele, 2009). The same frame can be accepted by groups of people with opposite views on a topic. Nisbet (2009) uses the example of stem-cell research, in which opponents and supporters of stem-cell research both use an ethical frame to support their respective positions. Some opponents argue that stem-cell research is immoral because of religious beliefs, whereas some supporters argue that preventing stem-cell research is immoral because of the medical discoveries that are being inhibited by halting research (Nisbet, 2009). An article on stem-cell research that is ethically framed may have a better chance of reaching both opponents and supporters of stem-cell research (Nisbet, 2009). In this way, framing can be a means to approach polarizing or gridlocked topics by providing "a context for dialogue, or to nudge public support toward policies informed by science and that solve collective problems" (Nisbet & Sheufele, 2009, p. 1771). Nudging support towards policies is a large burden to carry, and should be done with caution, if at all. Some publications prohibit writers from pushing towards a particular policy. If a publication allows for advocacy, science journalists should be transparent and clear when they are advocating for a particular position. If a writer advocates for a position covertly, he or she runs the risk of losing credibility and trust from readers.

One frame that is consistently unsuccessful in reaching an audience is the 'sound science' frame, or the idea that science has proven a path of action, and this path should be followed without regard to anything else (Nisbet, 2009). The "sound science" frame is unsuccessful because it does not leave room for the values of the audience, which may be more important to them than "sound science" could ever be; this approach effectively blocks a large part of the audience from engaging with the issue (Nisbet, 2009). In fact, by using moral and religious framing instead of "sound science" framing, "several scientists have convinced religious leaders that understanding the science of climate change is directly applicable to questions of faith" (Nisbet, 2009, p. 56). This example shows the potential power of framing when implemented successfully.

Another way to connect ideas, highlight relevance of a topic, and gain interest is through the use of narrative (Norris, Guilbert, Smith, Hakimelahi, & Phillips, 2005). As described in a peer-reviewed article, narratives are easier to understand (for adults and children) than expository texts (Norris & Phillips, 1994). Narrative is "a meaning structure that organizes events and human actions into a whole, thereby attributing significance to individual actions and events according to their effect on the whole" (Polkinghorne, 1988, p. 18). In other words, narratives are stories that involve events and characters.

Good narrative uses descriptive details in order to bring the story to life, such as what a character is wearing, feeling, or seeing (Knudson, 2006). These details allow readers to immerse themselves in the story (Knudson, 2006). Narratives also have a central character (Giles, 2002), which may or may not be human (Giles, 2002; Kunzig, 2006). Quotes are a crucial component of good narrative, because they:

> Bring your story to life, are authoritative, raise provocative questions. Quotes are heartbreaking, whimsical, funny. Quotes make the complex understandable. Quotes give the other side of the story. Conversational quotes help set the rhythm of a narrative. If you put a quote in a story that does none of these things, strongly consider taking it out. (Knudson, 2006, p. 31-32)

With respect to sentence structure, "Narrative pieces want sentences strung banjo-taught then backed-off a bit to ease comprehension" (Giles, 2002, p. 8). The use of humor in narrative can also be an effective way to engage a reader or to lighten what might otherwise be a heavy topic (Kunzig, 2006).

The formula for narrative is limited, (Giles, 2002) and consists of an original situation, followed by change, which may or may not result in a revelation (Norris et al., 2005). This loose structure can take many forms, which allows for creativity in writing. Narrative describes events that happened in a specific order; however, the order in which the author reveals the events, or the "discourse-time," is different (Norris et al., 2005). Time manipulation is a narrator's greatest tool. A narrator selects the discourse-time in order to create suspense, anticipation, and interest through flashbacks, flash-forwards, and foreshadowing (Norris et al., 2005).

Narratives are particularly useful because they help people understand the world, and it provides information in context (Norris et al., 2005). The purpose of narrative is for "communicating knowledge, feelings, values and beliefs" (Phelan, 1996, p. 18). This purpose fits perfectly with communicating a scientific message, "albeit one limited to fields where it is necessary to detail a set of unique, contingently and causally linked events in order to make a particular event or phenomenon clear, understandable, or intelligible" (Norris et al., 2005, p. 552).

Accurate Reporting. Without accurate reporting, all of the tools and tricks of the trade provided so far are useless to a science communicator. Accurate reporting boils down to citing information and making sure that the selected sources of information are reliable, as well as fact checking to make sure the writer's version of the facts are accurate. After writing a piece, the writer should be able to go line by line and identify the source and credibility of the information (Giles, 2002). Primary resources are crucial, especially peer-reviewed journal articles, because they present more stable information than secondary resources such as popular science articles (Lewenstein, 1995). Currently, peer-reviewed journal articles are not referenced as frequently because many journalists lack the scientific skills or training to interpret them (Treise & Weigold, 2002).

Some journalistic practices and conventions also get in the way of communicating accurately. One tendency in journalism is to only report on breakthroughs or controversy, which may leave out science that is significant and meaningful for the public (Bryant, 2003). As Treise and Weigold (2002) describe, "Editors and reporters tend to value stories that contain drama, human interest, relevance, or application to the reader, criteria that do not always map easily onto scientific importance" (p. 313). As well as selecting more newsworthy science, journalists have a tendency to sensationalize science by interpreting or reporting the science as more certain than it actually is (Gross, 1994; Macdonald, 2005). This certainty bias can be reduced by spending more time discussing scientific methods, recognizing the tentativeness of results, and justifying reasoning behind concepts (Macdonald, 2005). While discussing the methods, it is important to communicate the generalizability of the data to a larger population by describing the sample size and characteristics of the study population (Pellechia, 1997). Also, it is crucial for accurate reporting to contextualize new research or scientific findings within past relevant research (Pellechia, 1997). The trick is to find ways to include more methods and relevant research while still maintaining reader interest.

Another reporting convention is to show two (or more) sides of an issue in order to prove the author of the article is not biased. When reporting on science issues, this approach may lead to inaccurate reporting (Polman, Newman, Saul, & Farrar, 2014). Polman et al. (2014) describes how "good science reporters and editors recognize when something is consensus science, and even if there is another side, the consensus needs to be recognized as such, and more marginal positions should be downplayed" (p. 772). This does not mean that multiple perspectives cannot be presented or evaluated based on beliefs and values outside of the scientific community; however, claiming that the scientific community is divided, when it is not, is inaccurate reporting.

While it is important that the writer fact check every line of an article, it is even more important that a reader can see where the information is coming from. This accountability to the reader builds trust in the author of the article (Alsop, 1999). Readers can evaluate the credibility of sources for themselves if journalists follow proper attribution procedures. Polman et al. (2014) identify the components of an attribution as a description of why the information is important, along with a description of the source of information and how that source may be biased. If the source is a person, the attribution should include a description of the person's affiliations as they relate to the topic being discussed (Polman et al., 2014).

Literature Review Summary

The effective science journalism practices described above are directly tied to the theory behind science communication. The contextual model highlights the importance of making information relevant for readers. Without this relevance, or contextualization, readers may dismiss new information. In the practice of science journalism, articles may be made relevant by framing information or through the use of narrative.

The contextual model, unlike the deficit model, does not assume that the general public trusts science or science communicators; instead, trust must be built through accurate reporting techniques. Sources must be cited, and a source's credibility must be made evident through proper attribution. One thing that hasn't changed in the shift from the deficit model to the contextual model is the need for science to be communicated clearly. Clear communication can be achieved by using short sentences with active verbs, everyday language, metaphors, and easily digestible statistics. For a summary of the tools described in the literature review, and how each tool is related to the theory of science communication, please refer to Table 1. This table summarizes the theory outlined by the contextual model, as well as tools identified by the literature review to put this theory into practice.

Table 1.

Putting Science Communication Theory into Practice

Theory	Practice
Clarity (Blum, 2006; Finkbeiner, 2006; Giles, 2002; Sevian & Gonsalves, 2008; Spinks, 2001; Stocklmayer et al., 2001)	Everyday language (Baron, 2010) Metaphors and analogies (Dunwoody, 2006) Examples and non-examples (Baron, 2010) Methods for reporting data (Baron, 2010)
Relevance and Interest (Baron, 2010; Nisbet & Mooney, 2007)	Frames (Nisbet & Mooney, 2007) Narrative (Norris et al., 2005)
Accuracy (Alsop, 1999)	Primary resources (Treise & Weigold, 2002) Report uncertainty (Macdonald, 2005) Attribute sources (Polman et al., 2014)

Effective science journalism is as much an art as a science. Science journalism can be improved by implementing the effective practices described above in order to make writing more clear, accurate, relevant and interesting; however, effective science journalism is more than simply following a set of prescribed practices. If writers could achieve effective science journalism by checking off prescribed practices, then everyone would be good at it. Instead, it is crucial that creativity is part of the process. Like any creative endeavor, there are many ways to approach science journalism. This literature review is a road map to effective practice. It is not step-by-step directions to reach the final destination. The key is that the writer writes clearly, accurately, and with relevance and interest. It is up to the writer to decide which roads or turns to take to accomplish these goals, and how long it will take to get there. The roads that writers take are the results of their creative processes.

Chapter 3

Discussion and Reflection

This chapter includes three sections: a reflection on the process of writing the article, the article with comments describing how I incorporated what I learned in the literature review into the article, and a conclusion reflecting on the entire process of researching literature and using that literature to inform an article. The article, as it appears in the magazine, is located in Appendix A.

Preparing and Writing the Article

Research and interview process. This project, where I incorporated what I learned from a literature review into an article for *Western Confluence*, placed emphasis on writing the article, or the actual act of placement of words on a page, even though there is a lot more to the practice of science journalism. I did not include literature on how to research information or how to conduct interviews. I focused on how to write science journalism articles, because I was primarily interested in improving my writing skills. With that said, it is important to discuss how I researched the article and gathered resources, because it is a large component of the journalism process.

The first step was to find as much information on the introduction of lake trout, and the subsequent ecosystem effects, as possible. I read popular science articles to see how journalists had presented the information already, and I read primary peer-reviewed research articles on the topic to gather the most reliable scientific information on the topic. During the initial stages of research, I immersed myself in the information and collected as much as I could find.

After organizing the information, I looked for gaps in knowledge, as well as opportunities to bring in voices of people who care about the issue, and I created a list of experts who I wanted to interview. For each expert, I wrote a list of questions to ask in the interview. The questions for the fisheries biologists were very different from the questions I asked the commercial fisherman or the research biologist, because I wanted to gather specific information from each of these experts. For example, I wanted to know about the process of catching fish from the fisherman, and I wanted to know the science behind the lake trout control efforts from the fisheries biologists. My questions were directed to explore these topics.

Occasionally, an interview led to more questions, and I would to go back to the research or find another expert to answer the questions. After interviewing Bob Gresswell, a fisheries biologist, I realized I needed a perspective from the National Park, and so I reached out to Pat Bigelow, the fisheries biologist for Yellowstone National Park. After typing up all of the interview notes and creating a list of useful quotes from each interview, I was ready to create an outline for the story. Throughout this entire process, Emilene Ostlind mentored me. Emilene edited my lists of questions and suggested new ones. She recommended people that I should interview and put me in touch with those people.

Writing the article. During the initial stages of writing, I wanted to make sure that I did not stifle my own creativity by thinking too much about what I had learned in the literature review. I created an outline; Emilene gave me feedback, and I wrote the first draft. After I finished the draft, I revisited the literature review and incorporated effective practices and theory where I felt they were appropriate. The theories of effective science communication form the foundation of the article. I was constantly thinking about how to make the information relevant, interesting, meaningful, and useful for the audience, and I used effective practices of science journalism (where appropriate) to achieve these goals. Many effective practices were already present, even though I did not consciously put them in, such as the use of active voice or narrative.

I did not try to fit everything I learned into the article. I only used certain strategies if they made sense to me. In this way, the literature review really was a road map, and I chose the route that I wanted to use for this particular article. The literature review was never meant to be a checklist of tools that must be used in an article. Every article is unique, and not every tool is useful for every situation. For these reasons, the literature review aided my writing, but it did not completely dictate what I wrote or what tools I chose to use. I treated the effective practices like tools in a toolbox. I didn't use a hammer when the job called for a screwdriver.

For example, Finkbeiner's AB/BC rule makes sense to me in certain applications; however, if I structured the entire article with this rule, the article would be boring. Instead, I used the AB/BC rule in a string of sentences to guide the reader through a logical progression. I also departed from the best practices identified by the literature review when I decided not to report on the statistical significance of the findings. I decided that for this particular article, explaining significance would appear as a digression from the article.

Narrative is the primary tool employed by *Western Confluence* to bring natural resource issues to life, contextualize information, and hold the reader's interest and attention, and it was therefore a foundational component of my article for *Western Confluence*. Using narrative allowed me to build suspense, and it also helped me draw the reader into the story. I also use narrative to portray Arthur Middleton, one of the scientists, as a detective. Perhaps by sharing Middleton's story and his methods of discovery, the audience realizes that scientists are ordinary people. The narrative may help the reader understand how science works, and it may engage readers that are typically not interested in science.

After integrating effective theory and practices that I deemed appropriate for the article, I sent the next draft to Emilene for the first of many editing rounds. Emilene's initial edits were structural. She suggested that I switch the order of the paragraphs, adjusting the 'discourse time' that I had initially created. Her changes created more suspense and generated more interest for the reader. Instead of starting with the description of the commercial fishermen on Yellowstone Lake, the second draft started with a mystery of missing elk. I incorporated Emilene's structural edits in the following draft, and I clarified areas that Emilene found confusing.

Emilene's edits on the next draft were primarily at the sentence level. These edits made sentences clearer by finding ways to say the same thing with fewer words. Emilene also highlighted areas where transitions needed to be stronger, or where more information was needed. The subsequent rounds of editing were polishing rounds. There were no large changes, but Emilene and I scrutinized every sentence and word selection. I frequently returned to the literature review to make sure I was incorporating what I had learned where I deemed it was appropriate. Emilene's edits were always in line with the tools that I had learned from the literature review, which made the process run smoothly. The following section includes a draft of the article completed on April 30th, 2015, as well as comments that highlight areas where I incorporated what I learned from the literature review into the article. The article will appear in its final form when it is published in June of 2015.

Article with comments

On the left column is the article "A Tale of Two Migrations: The Splash of One Fish Ripples Through an Ecosystem," and on the right column are comments describing how I integrated what I learned from the literature review into the article. The final version of this article will be published in *Western Confluence* in June, and may have minor changes from this version. Throughout the comments section, I did not make a comment every time that I used a tool from the literature review in the article in order to avoid redundancy. For example, I did not highlight every time I crafted a short sentence for clarity. Instead, I highlighted quality examples of the tools that I used throughout the article.

Article (Draft: April 30th, 2015)	Comments
In 2007, biologist Arthur Middleton was studying the Clark's Fork elk herd, which migrates between Yellowstone National Park and the foothills northwest of Cody, when he made a perplexing discovery. Surveys were documenting about half as many calves as historically observed on the elk's winter range near Cody. At first, biologists speculated that wolves were targeting vulnerable elk calves during the winter. However, when the elk returned in the fall from Yellowstone National Park, there was a surprise—the calves were already missing. The wolves on the winter	As I described in the theory of science communication, it is important to find ways to make information relevant and interesting to motivate the audience to read the article. The opening uses narrative to engage the reader, which has a character (Arthur) and a topic (the missing elk calves). The narrative generates suspense and interest by giving just enough information to hook the reader. Arthur is the central character of this narrative, and the reader is left wondering how Arthur will solve the mystery. I start the article with a mystery of

range were not the culprit. "Something was going on up in Yellowstone," Middleton described, and he set out to solve the mystery.	missing elk calves, because many of the readers of *Western Confluence* care about Wyoming's big game (whether they are hunters or wildlife enthusiasts). Describing Arthur's process of scientific discovery throughout the rest of the article helps readers understand that Arthur is an ordinary person that happens to do scientific research. If a reader is typically not interested in science, this approach may help them engage with science in a way that they have not engaged in the past.
Middleton, who received his doctorate in 2012 from the University of Wyoming studying elk in northwestern Wyoming with the Cooperative Fish and Wildlife Research Unit, had an idea of where to start. As a biologist, he knew that grizzly bears were the primary predator of newborn elk calves, and that recent research was documenting a shift in grizzly bear diet. This spurred him to dig into historic research on grizzlies to find out if this	The first sentence of the second paragraph follows proper attribution procedures, giving all of the information needed to show the credibility of the source and establishing the reliability of the information. It also serves to further develop Arthur as a character in the narrative. This paragraph includes a conversational quote from Arthur to bring the story to life and to help set the rhythm of the narrative.

shift in diet could explain the missing elk calves. "I found myself fascinated by the interactions. I read through dozens and dozens of old papers, going back into the 70s and the 80s and the 90s, and digging through the library for the stuff that wasn't online, and really getting deep into the history of studies that compare diets. I exhaustively used everything we knew about bear diet so that I could compare historical diets to contemporary diets."	
Through his investigation, Middleton started to piece together an intricate food web of interactions. Grizzly bears eat a wide variety of foods, from moths and berries to full-grown elk and moose. Their diet is limited seasonally as different foods become available. In the spring, the bears surrounding Yellowstone Lake focus their foraging efforts on spawning Yellowstone cutthroat trout. That is, they did until the cutthroat population plummeted in the mid-1990s.	I describe the ecology of grizzly bears in everyday language without the use of jargon. Instead of using the words "omnivore" and "opportunistic," I describe the eating habits of grizzly bears with phrases such as "a wide variety of foods" and "limited seasonally." This paragraph starts a second narrative of the ecosystem interactions between different organisms. In this narrative, there is not a human character. The characters are the animals in the ecosystem. This paragraph ends

	with another cliffhanger to generate interest and to encourage the reader to keep reading to find out why the cutthroat trout population is declining.
In 1994, scientists discovered lake trout, a non-native fish species, in Yellowstone Lake. It is widely thought that rogue fishermen introduced them to the lake in the mid 1980s for sport fishing. Adult lake trout primarily eat other fish, and in Yellowstone Lake, they eat Yellowstone cutthroat trout. Since the invasion, lake trout have wreaked havoc on the native trout. As lake trout populations rapidly increased, cutthroats started to disappear. When combined with the effects of drought and whirling disease, which is caused by a parasite that has decimated trout throughout the west, the cutthroat population has reached dangerously low numbers.	The first sentence of this paragraph defines lake trout, because many readers may not know what they are or why they matter in the context of the narrative. Some audiences may not understand what "non-native" means, but it can be deduced by the following description that they were introduced to the lake (i.e. they do not belong there). The article manipulates the order of events to generate suspense. I start with a scene from 2007, and here the article goes back in time to 1994.
Cutthroat trout are a crucial component	This paragraph describes why the reader

of the surrounding ecosystem, and lake trout do not fit into the food web in the same way. In the spring, cutthroats migrate up tributaries to spawn where they are exposed to grizzly bears, osprey, otters, and over 30 other native predators. Unlike cutthroat, lake trout do not spawn in streams. Instead, they spawn in Yellowstone Lake in the fall, out of reach of bears and other predators.	should care about the disappearance of cutthroat trout through an "ecological importance" frame. This frame will resonate with an audience that values ecosystems for their inherent value. Later in the story, more frames are used to help readers from different backgrounds contextualize and give meaning to the information.
As cutthroat numbers dwindle, the many species that once relied on them in the spring have lost a major spring food source. The grizzlies have turned to newborn elk calves to supplement their diet. The most recent research Middleton uncovered, published by the Interagency Grizzly Bear Study Team, indicated that grizzly bears near Yellowstone Lake are eating more elk calves than ever, and that this shift is due to the decline of Yellowstone cutthroat trout.	
Middleton had something to add to the conversation. "What the people who	Now the article transitions back to the narrative with Arthur as the primary character,

documented [this shift] didn't know, that I knew, is that if grizzly bears are switching from cutthroat trout to elk calves in the watershed of Yellowstone Lake, … they can only be eating the calves of migratory elk." Middleton said. "I sort of came into the picture and said, wow, you know, this effect, this change in the grizzly bear diet, is something that could be transmitting all the way out to places like Cody and Jackson and Paradise Valley, because these are migratory elk herds."	and the two narratives are combined. The quote is used to reveal Middleton's role in uncovering a new aspect of the ecological food web story described above. The quote also reveals the importance of Middleton's realization.
Middleton wanted to find out what the shift in grizzly bear diet would mean for the migratory elk. To do this, he used his detective work with historic research papers to estimate how many trout and elk calves the bears used to eat, and compared that number to how many trout and elk calves the bears eat today. To compare the number of elk calves from year to year, Middleton looked at what biologists call the "cow/calf ratio," that is, the number of calves per 100 cows, which indicates the reproductive success of a herd. Historically,	The description of Middleton's methods is informed by personal communication with Middleton, as well as reference to the primary literature of his peer-reviewed journal article to ensure accurate reporting.

biologists documented 30 to 35 elk calves for every 100 cows in the Clark's Fork herd.	
Middleton, working with a University of Wyoming postdoc, Tom Morrison, used this information to create a computer model that could calculate whether the bears' shift in diet was enough to actually impact the elk herd. The surveys starting in 2007 had documented a drop to 10 to 15 elk calves per 100 cows. Of the 15 to 20 missing elk calves per 100 cows, Middleton's model predicted that the observed shift in bear diet accounted for 3 to 4 them. This may sound like a small number, but to an ecologist, it matters. Middleton described the implications with excitement: "You know, wow, trout 70 miles away can affect how many elk calves there are. It is just kind of crazy."	The description of the cow/calf ratio is necessary in order to allow the reader to interpret the results. In order to explain the cow/calf ratio idea, I include every piece of information. I do not simply state: "Of the 15 to 20 missing elk calves per 100 cows, Middleton's model predicts that the observed shift in bear diet can account for 3 or 4 of them." I give the reader the tools needed to understand what these numbers mean. I also convert Middleton's results, which were described in the percent decline in calf recruitment, into cow/calf ratios to make the results more digestible. Readers might have difficulty understanding a "4-14% decrease in elk calf recruitment", but "3-4 missing calves" is easier to understand. I then pair the results with a quote from Middleton in order to show the importance of the results. I do not include the statistical significance of the results,

	because it would take away from the momentum of the article.
The remaining missing elk calves may be due to drought (which reduces the available forage), increased grizzly bear populations, and wolf predation. Although a shift in grizzly bear diet does not entirely explain the observed decline in elk calves, it is playing a role.	It is crucial to include other confounding or contributing causes behind scientific observations so that the audience can understand the results in the context of existing research. Omitting such information would be inaccurate or misleading reporting, and may imply bias. This paragraph recognizes that more factors than a shifting grizzly bear diet are responsible for the missing elk calves. This paragraph also prevents Middleton's results from being sensationalized by showing that a shift in grizzly bear diet is affecting elk, but there are many other things that are also affecting elk.
In April of 2013, Middleton published his research, adding elk to the list of species affected by the lake trout invasion. Meanwhile, contract fishermen were gearing up for yet	This paragraph transitions to the third narrative, which is the human effort to remove lake trout on Yellowstone Lake.

another season of lake trout removal on Yellowstone Lake, as they had been doing for the past four years.	
The ice on Yellowstone Lake typically goes out in late May, and contract fishing operations start as soon as the water is open. Three fishing boats with four fishermen each set out from shore at dawn. The boats are equipped with hydraulic lifts to raise miles of gillnet that have been set in the lake overnight. As the fishermen draw the nets out of the water, sun flashes off slabs of silver—a good haul. The fishermen grasp the frigid, slime-covered fish and remove them from the nets. This is not your typical contract fishing operation—these fishermen are in the heart of the nation's first National Park, and these fish will never see a dinner plate. Instead, their carcasses are destined for the bottom of Yellowstone Lake.	This narrative uses vivid imagery and descriptive details. The end of the paragraph also generates suspense by withholding information that will be explained later.
"Part of the Park Service mission is to conserve natural resources, and conserving the	This paragraph introduces another frame to view the disappearance of cutthroat trout:

Yellowstone cutthroat population within Yellowstone Lake is a huge portion of our natural resources, especially in the fisheries," explains Patricia Bigelow, fisheries biologist for Yellowstone National Park who has been part of the lake trout control program on Yellowstone Lake for the past fifteen years.	cutthroat trout as a natural resource. Readers who value the conservation of natural resources may be able to identify with this framework.
"The problem is the lake trout predation, so if you want to help the cutthroat trout population, *that* is what you need to address," Bigelow continues, "The goal is to suppress the lake trout population to the point that the cutthroat population can rebound."	
Yellowstone cutthroat trout, named for the red gashes of color slicing underneath their jaws, are highly valued fish. Anglers come from all over the world to fish for this black spotted, golden-red trout that can only be found in the Greater Yellowstone Ecosystem. Hundreds of thousands of Yellowstone National Park visitors once watched from Fishing Bridge on the Yellowstone River as teams of spawning trout jockeyed for position.	This paragraph employs three frames for recognizing the importance of Yellowstone cutthroat trout. The first frame is geared towards fishermen, the second frame towards visitors of the national park, and the third re-visits the ecological frame introduced earlier in the article. These frames are used together to explain why the Park Service has a lake trout control effort.

And as researchers have shown, cutthroat trout are a crucial component of the food web. For these reasons, the park service has gone to war against the lake trout invasion.	
In 1995, the Park Service invited a panel of scientists to assess the severity of the situation and advise the control efforts. The panel advised the park to remove lake trout, and the park started the efforts immediately. In 2008, the science panel reconvened and advised the park that it was on the right track, and it needed to do even more to stop the lake trout population growth. In response, the park tried hiring contract fishermen to harvest lake trout, and has continued to increase the control effort every year. By 2012, the park reached control levels recommended by the science panel. Middleton published his research in 2013, providing further fuel for lake trout control efforts and inspiring bumper stickers proclaiming 'Lake Trout Kill Elk.'	This paragraph provides a timeline of events that lead up to current control efforts. Timelines are crucial components of narrative. It also puts Middleton's research in the context of this new narrative of lake trout control.
Today, the park contracts the Hickey	"130 days of fishing" and "over two

Brothers from Wisconsin to net lake trout every day from ice off until early October, roughly 130 days of fishing every year. On average, the fleet of three boats catches over two thousand fish every day. The fishermen kill the lake trout (if they aren't already dead), count them to monitor the population, pop the air bladder so that the carcass will sink, and dump the fish in the deepest sections of the lake.	thousand fish" are powerful statistics worth reporting. I convert the number of weeks of fishing to days to report the number in the strongest possible form.
The Park, with the help of the Hickey Brothers, has deposited metric tons of fish in Yellowstone Lake in the hopes that these carcasses will keep nutrients in the system. Bob Gresswell, a research biologist who served as chair on both science panels and has been studying Yellowstone cutthroat trout with the park and the US Geological Survey since 1974, says there is no evidence that dumping the fish into Yellowstone Lake is harmful; however, some scientists are concerned that it may be altering the ecosystem in unpredictable ways. Further research is needed to understand the	This paragraph is one of many areas where I invite the reader to critically engage with the information. As a writer for *Western Confluence*, I cannot state my own opinion. I have to use quotes from other people if I want to bring up a particular opinion. In this paragraph, I use Gresswell's opinion to bring up the uncertainty of the science behind 'nutrient loading.' According to the theory of effective science communication that I describe in the literature review, it is crucial to make people think critically about information,

impacts of this "nutrient loading."	which is something that I consciously strive for throughout the article. I do not want people to take this information at face value. I provide enough information so that people can decide for themselves how the park should be managing lake trout, and I present that information in an interesting and relevant way so that people will retain and use the information.
Gillnetting removes fish efficiently, but not without consequences, including by-catch of Yellowstone cutthroat trout. The fishermen reduce the amount of by-catch by adjusting the gillnet mesh size. They also focus on areas of the lake that have high densities of lake trout and very few cutthroat trout. The science panel closely monitors by-catch to ensure that it does not exceed levels that could negatively impact the cutthroat trout population. Additionally, if a cutthroat is caught in a net, the fishermen attempt to return it safely to the lake. Even so, over half of the cutthroats caught in the nets	

will die.	
Gillnetting is also expensive. Lake trout control costs the park over a million dollars annually. And if the park ends the program today, all of the progress will be lost. "All of our modeling shows that if you cut back at any point in time, the lake trout will begin to increase again," Gresswell explains, "The suppression of lake trout is something that will always have to occur in Yellowstone Lake. It has to become something that is just part of the working budget of Yellowstone Lake, just like plowing the roads, or cleaning the bathrooms and the campgrounds."	The first three sentences are short, making the information clearer and also more memorable. The quote from Gresswell employs an analogy, and is useful to put lake trout control efforts into perspective for the reader. Most likely, it will be jarring for a reader to hear an expert comparing the slaughtering of fish to plowing roads and cleaning bathrooms. This is another section that promotes the reader to process the information through a critical lens.
The park is testing cheaper and more efficient ways to control lake trout. One alternative uses large grids of electric wires to zap embryos and emerging fry in lake trout spawning areas. Another uses a mining dredge to suck the embryos out of spawning beds. These alternatives show promise by eliminating by-catch, but they still cannot	This paragraph uses active verbs, including "zap," "suck," and "eliminate." These verbs help paint a picture of the actions the park is taking.

completely remove lake trout from the system.	
Future technologies may provide the solution. Gresswell suggests that "emerging genetic technologies" could help eradicate lake trout from Yellowstone Lake. One solution scientists are developing is to genetically alter male lake trout so that they can only produce male offspring. The idea is that the park would continually stock Yellowstone Lake with these genetically altered males while maintaining gillnetting efforts to control the overall population. With several decades of stocking altered males and gillnetting, the park may be able to eradicate lake trout.	This description is a good example of providing all of the logical steps and information so that the reader can understand how genetically modified trout could lead to complete removal of lake trout from the ecosystem.
Even without new technology, "There are lots of very positive signs that this suppression activity is beginning to accomplish its goal," explains Gresswell. Population models suggest that the current level of lake trout harvesting is working. Bigelow states that "it is really exciting that population modeling is showing a decline in the lake trout	This paragraph is the beginning of the conclusion. The final paragraphs anticipate questions that readers may still have, such as- "is lake trout control working?" "What does the recovery of cutthroat trout mean for the ecosystem?" and "Why should I care about this information?"

population overall," and Gresswell is hopeful that "we should see a relatively rapid, within decades, resurgence of cutthroat trout."	
When irresponsible fishermen introduced lake trout in Yellowstone Lake, they could never imagine the consequences of their actions. Over thirty years later, the lake trout effect is still rippling through the ecosystem in surprising ways. "These cutthroat trout are not just important because they're native fish," Middleton said, "they are important because they are at the heart of a … web of interactions that reaches all the way to elk in the outskirts of the Greater Yellowstone Ecosystem that are economically, recreationally, and culturally immensely valuable." But even with cutthroat trout rebounding, this web of interactions may never be the same again.	This paragraph uses a quote from Middleton to frame the issue in terms of the importance of elk. This frame helps to reach audience members who may not care about some of the ecological frames, but may be very interested in how these resources can be useful to humans.
Bringing cutthroats back to historic levels would be a huge accomplishment for the park. But whether or not the resurgence of	The article concludes with a thought-provoking quote from Arthur Middleton. This conclusion invites the reader to process the

cutthroats will restore the ecosystem is uncertain. “We can’t go around complacently thinking that we have restored Yellowstone. We are not going back to a baseline; we are not fixing it to where it was. We are all going somewhere new,” explained Middleton, “And that’s as sad as it is exhilarating.”	information and think critically about what the ‘trout effect’ means for them.

Conclusion

Three goals guided this project: to better understand science communication theory as the foundation for science journalism, to educate myself on current effective science journalism practices, and to incorporate what I learned into an article for *Western Confluence* magazine. As illustrated by the previous section, I achieved these goals. The literature review was useful, because what I learned impacted my writing. My entire approach was dictated by the theory of effective science communication. I started by brainstorming all of the ways that the story is relevant and interesting to the audience. The needs and interests of the audience served as a scaffolding to build the outline of the story. I focused on making the information relevant to anglers, hunters, and visitors to the National Park. As I wrote, I found myself catching sentences I had written in passive voice, and I changed them to active voice. I also structured the story to generate interest.

Along with making me a better writer, the literature review helped me understand the edits Emilene provided. When she restructured the story line, I understood how it adjusted discourse time and made the story more suspenseful. I could see how changes in verb choice made sentences more active. When she shortened sentences, I could see how the use of fewer words made the message clearer. Although I had learned about all of these concepts, it was not always easy for me to identify where these concepts should be applied in my own writing.

Throughout this project, it was a constant struggle to decide when to consciously incorporate what I learned into the article, and when to give myself creative license. I found a balance by writing without referencing the literature review, and then editing with the literature review as a road map. I constantly made decisions about when it was appropriate to use a particular tool from the literature review. In this way, I acknowledged that writing is both an academic and artistic endeavor.

It will be interesting to see how the field of science communication will evolve in the future. The theory of the contextual model values scientific knowledge equally with the local knowledge of the public; however, in the practice of science journalism, this may not be the case. In my own writing, I implicitly placed more value on scientific knowledge because I didn't include any voices from people outside of the scientific community. I did not intentionally exclude voices of the general public, but I also did not seek them out. For the ideals of the contextual model to fully permeate into the practice of science journalism, a new model that gives more weight to local knowledge might be necessary. Perhaps after overcorrecting the problems with the deficit model, the field will ultimately reach a balance between valuing scientific and public ways of knowing.

Through the process of writing the literature review and incorporating what I learned into an article, my approach, as well as my writing, has shifted and evolved. When I was writing the blog for the Graduate Program, I made an assumption that the audience was just as excited about science as I was. Instead of being explicit about why the information was relevant and interesting for my audience, I simply presented the science content. I was operating under the deficit model. After reading the literature and learning about the shift from the deficit model to the contextual model, I realized that not everyone is as passionate about science as I am. A major role of the science journalist is to show the audience why they should care about the information, and I did not realize this until I engaged critically with the literature in the field of science communication. With *Western Confluence*, my writing has been founded upon the needs and the interests of the audience. In the article on lake trout introduction, I started by brainstorming all of the people that would be interested in the topic, as well as the frameworks that these people might use when thinking about lake trout introduction. I then framed the article with these contexts in mind. In this way, the shift in my own practice of science journalism has reflected the shift in theory from the deficit model to the contextual model.

The process of writing the literature review and article has given me a deeper understanding of the canyon metaphor of science communication, as well as my own role as a science communicator. Not only must science communicators rappel into the canyon to retrieve scientific articles, but they also must climb the canyon wall to reach the other side and talk directly to the scientists. Communicating with scientists was huge component of accurately writing the article for *Western Confluence*, and I found it easy to do because of my knowledge and experience in the field of biology. This project, when combined with my science background, has empowered me to effectively bridge the canyon between the general public and the world of science.

The greatest result of this project is that it equipped me with the tools, confidence, and knowledge I need to pursue a career in the field of science communication. The mentorship, guidance, and editing I received from Emilene Ostlind was invaluable, and when paired with the process of writing a literature review and applying what I learned in an article for *Western Confluence*, I feel prepared for a career in science communication. I set out to craft an article that reflects what I have learned, and also represents the current effective practice of science journalism; I accomplished these goals, and I also prepared myself for the next step in my professional development as a science communicator.

References

Alsop, S. (1999). Understanding understanding: A model for the public learning of radioactivity. *Public Understanding of Science, 8*, 267-284.

Analogy [Def. 2a]. (n.d.). In *Merriam Webster Online*, Retrieved March 11, 2015, from http://www.merriam-webster.com/dictionary/analogy.

Baram-Tsabari, A. & Osborne, J. (2015). Science education and science communication research. *Journal of Research in Science Teaching, 52*(2), 135-144.

Baron, N. (2010). *Escape from the ivory tower: A guide to making your science matter*. Washington, DC: Island Press.

Blum, D. (2006). Ten time-tested tips. In D. Blum, M. Knudson, & R.M. Henig (Eds.), *A field guide for science writers* (pp. 27-28). New York: Oxford University Press.

Bryant, C. (2003). Does Australia need a more effective policy of science communication?. *International Journal for Parasitology, 33*, 357-361.

Burns, T. W., O'Connor, D.J., & Stocklmayer, S.M. (2003). Science communication: A contemporary definition. *Public Understanding of Science, 12*, 183-202.

Dunwoody, S. (2006). On explaining science. In D. Blum, M. Knudson, & R.M. Henig (Eds.), *A field guide for science writers* (pp. 27-28). New York: Oxford University Press.

Durant, J. R., Evans, G. A. & Thomas, G. P. (1989). The public understanding of science. *Nature, 340*, 11-14.

Finkbeiner, A. (2006). On writing clearly and logically. In D. Blum, M. Knudson, & R.M. Henig (Eds.), *A field guide for science writers* (pp. 28-30). New York: Oxford University Press.

Giles, B. (2002). Sharing the secrets of fine narrative journalism: Those who do it well explain what it is they do. *Nieman Reports, 56*(1), 7-9.

Gross, A. G. (1994). The roles of rhetoric in the public understanding of science. *Public Understanding of Science, 3*, 3-23.

Guyer, R. L. (2006). Storytelling. In D. Blum, M. Knudson, & R.M. Henig (Eds.), *A field guide for science writers* (pp. 30-31). New York: Oxford University Press.

Jenkins, E. W. (1994). Public understanding of science and science-education for action. *Journal of Curriculum Studies, 26*(6), 601-611.

Knudson, M. (2006). Storytelling. In D. Blum, M. Knudson, & R.M. Henig (Eds.), *A field guide for science writers* (pp. 31-32). New York: Oxford University Press.

Kunzig, R. (2006). Gee whiz science writing. In D. Blum, M. Knudson, & R.M. Henig (Eds.), *A field guide for science writers* (pp. 126-131). New York: Oxford University Press.

Lewenstein, B. V. (1995). From fax to facts: Communication in the cold fusion saga. *Social Studies of Science, 25*(3), 403-436.

Lewenstein, B. V. (2015). Identifying what matters: Science education, science communication, and democracy. *Journal of Research in Science Teaching, 52*(2), 253-262.

Macdonald, S. P. (2005). The language of journalism in treatments of hormone replacement news. *Written Communication, 22*(3), 275-297.

Metaphor [Def. 1]. (n.d.). In *Merriam Webster Online,* Retrieved March 11, 2015 from http://www.merriam-webster.com/dictionary/metaphor.

Miller, S. (2001). Public understanding of science at the crossroads. *Public Understanding of Science, 10*, 115-120.

Nelkin, D. (1995). *Selling science: How the press covers science and technology.* New York: W.H. Freeman.

Nisbet, M. C. (2009). The ethics of framing science. In B. Nerlich, R. Elliot, & L. Brendon (Eds.), *Communicating biological sciences: Ethical and metaphorical dimensions* (pp. 51-73). Burlington, VT: Ashgate Publishing Limited.

Nisbet, M. C. & Mooney, C. (2007). Framing science. *Science, 316*(5821), 56.

Nisbet, M. C. & Sheufele, D. A. (2009). *American Journal of Botany, 96*(10), 1767-1778.

Norris, S. P., Guilbert, S. M., Smith, M. L., Hakimelahi, S., & Phillips, L. M. (2005). A theoretical framework for narrative explanation in science. *Science Education, 89*, 535-563.

Norris, S. P. & Phillips, L. M. (1994). Interpreting pragmatic meaning when reading popular reports of science. *Journal of Research in Science Teaching*, *31*(9), 947-967.

Office of Science and Technology and the Wellcome Trust. (2001). Science and the public: A review of science communication and public attitudes toward science in Britain. *Public Understanding of Science*, *10*(3), 319-334.

Paisley, W. J. (1998). Scientific literacy and the competition for public attention and understanding. *Science Communication, 20*(1), 70-80.

Pellechia, M. G. (1997). Trends in science coverage: A content analysis of three US newspapers. *Public Understanding of Science, 6*, 49-68.

Phelan, J. (1996). *Narrative as rhetoric: Technique, audiences, ethics, ideology.* Columbus, OH: Ohio State University Press.

Polkinghorne, D. E. (1988). *Narrative knowing and the human sciences*. Albany, NY: State University of New York Press.

Polman, J. L., Newman, A., Saul, E. W., & Farrar, C. (2014). Adapting practices of science journalism to foster science literacy. *Science Education, 98*(5), 766-791.

Reinertsen, C., Bao, K. H., Mitchell, S., Halvorson, K., Pappas, M., & Freedberg, S. (2015). Genetic variation and gene flow at the northern range edge of two riverine turtles.

Sevian, H. & Gonsalves, L. (2008). Analysing [sic] how scientists explain their research: a rubric for measuring the effectiveness of scientific explanations. *International Journal of Science Education, 30*(11), 1441-1467.

Shamos, M. H. (1995). *The myth of the scientific literacy.* New Brunswick, NJ: Rutgers University Press.

Shreeve, J. (2006). Narrative writing. In D. Blum, M. Knudson, & R.M. Henig (Eds.), *A field guide for science writers* (pp. 138-144). New York, New York: Oxford University Press.

Spinks, P. (2001). Science journalism: The inside story. In S.M. Stocklmayer, M.M. Gore, & C. Bryant (Eds.), *Science communication in theory and practice* (pp. 151-168). Dordrecht, Netherlands: Springer Science+Business Media B.V.

Stocklmayer, S. M., Gore, M. M., & Bryant, C. (2001). *Science communication in theory and practice*. Dordrecht, Netherlands: Springer Science+Business Media B.V.

Strauss, S. (2009). Metaphor contests and contested metaphors: from webs spinning spiders to barcodes in DNA. In B. Nerlich, R. Elliot, & L. Brendon (Eds.), *Communicating biological sciences: Ethical and metaphorical dimensions* (pp. 153-166). Burlington, VT: Ashgate Publishing Limited.

Treise, D. & Weigold, M. F. (2002). Advancing science communication. *Science Communication, 23*(3), 310-322.

Turney, J. (1996). Public understanding of science. *The Lancet, 347*, 1087-1090.

Wiederhold, B. K. (2011). Build trust, engage people to increase understanding of science. *Cyberpsychology, Behavior, and Social Networking, 14*(11), 629-630.

Wilkes, J. (2006). Storytelling. In D. Blum, M. Knudson, & R.M. Henig (Eds.), *A field guide for science writers* (pp. 32-33). New York, New York: Oxford University Press.

Appendix A

The following article is a draft produced on April 30th, 2015. The final article will be published in *Western Confluence* in June of 2015, and will include illustrations and formatting for the magazine. Once the article is published, I will update Appendix A with the final version of the article as it appears in the magazine.

A Tale of Two Migrations

The splash of one fish ripples through an ecosystem

In 2007, biologist Arthur Middleton was studying the Clark's Fork elk herd, which migrates between Yellowstone National Park and the foothills northwest of Cody, when he made a perplexing discovery. Surveys were documenting about half as many calves as historically observed on the elk's winter range near Cody. At first, biologists speculated that wolves were targeting vulnerable elk calves during the winter. However, when the elk returned in the fall from Yellowstone National Park, there was a surprise—the calves were already missing. The wolves on the winter range were not the culprit. "Something was going on up in Yellowstone," Middleton described, and he set out to solve the mystery.

Middleton, who received his doctorate in 2012 from the University of Wyoming studying elk in northwestern Wyoming with the Cooperative Fish and Wildlife Research Unit, had an idea of where to start. As a biologist, he knew that grizzly bears were the primary predator of newborn elk calves, and that recent research was documenting a shift in grizzly bear diet. This spurred him to dig into historic research on grizzlies to find out if this shift in diet could explain the missing elk calves. "I found myself fascinated by the interactions. I read through dozens and dozens of old papers, going back into the 70's and the 80's and the 90's, and digging through the library for the stuff that wasn't online, and really getting deep into the history of studies that compare diets. I exhaustively used everything we knew about bear diet so that I could compare historical diets to contemporary diets."

Through his investigation, Middleton started to piece together an intricate food web of interactions. Grizzly bears eat a wide variety of foods, from moths and berries to full-grown elk and moose. Their diet is limited seasonally as different foods become available. In the spring, the bears surrounding Yellowstone Lake focus their foraging efforts on spawning Yellowstone cutthroat trout. That is, they did until the cutthroat population plummeted in the mid-1990s.

In 1994, scientists discovered lake trout, a non-native fish species, in Yellowstone Lake. It is widely thought that rogue fishermen introduced them to the lake in the mid 1980s for sport fishing. Adult lake trout primarily eat other fish, and in Yellowstone Lake, they eat Yellowstone cutthroat trout. Since the invasion, lake trout have wreaked havoc on the native trout. As lake trout populations rapidly increased, cutthroats started to disappear. When combined with the effects of drought and whirling disease, which is caused by a parasite that has decimated trout throughout the west, the cutthroat population has reached dangerously low numbers.

Cutthroat trout are a crucial component of the surrounding ecosystem, and lake trout do not fit into the food web in the same way. In the spring, cutthroats migrate up tributaries to spawn where they are exposed to grizzly bears, osprey, otters, and over 30 other native predators. Unlike cutthroat, lake trout do not spawn in streams. Instead, they spawn in Yellowstone Lake in the fall, out of reach of bears and other predators.

As cutthroat numbers dwindle, the many species that once relied on them in the spring have lost a major spring food source. The grizzlies have turned to newborn elk calves to supplement their diet. The most recent research Middleton uncovered, published by the

Interagency Grizzly Bear Study Team, indicated that grizzly bears near Yellowstone Lake are eating more elk calves than ever, and that this shift is due to the decline of Yellowstone cutthroat trout.

Middleton had something to add to the conversation. “What the people who documented [this shift] didn’t know, that I knew, is that if grizzly bears are switching from cutthroat trout to elk calves in the watershed of Yellowstone Lake, … they can only be eating the calves of migratory elk.” Middleton said. “I sort of came into the picture and said, wow, you know, this effect, this change in the grizzly bear diet, is something that could be transmitting all the way out to places like Cody and Jackson and Paradise Valley, because these are migratory elk herds.”

Middleton wanted to find out what the shift in grizzly bear diet would mean for the migratory elk. To do this, he used his detective work with historic research papers to estimate how many trout and elk calves the bears used to eat, and compared that number to how many trout and elk calves the bears eat today. To compare the number of elk calves from year to year, Middleton looked at what biologists call the “cow/calf ratio,” that is, the number of calves per 100 cows, which indicates the reproductive success of a herd. Historically, biologists documented 30 to 35 elk calves for every 100 cows in the Clark’s Fork herd.

Middleton, working with a University of Wyoming postdoc, Tom Morrison, used this information to create a computer model that could calculate whether the bears’ shift in diet was enough to actually impact the elk herd. The surveys starting in 2007 had documented a drop to 10 to 15 elk calves per 100 cows. Of the 15 to 20 missing elk calves per 100 cows, Middleton’s model predicted that the observed shift in bear diet accounted for 3 to 4 them. This may sound like a small number, but to an ecologist, it matters. Middleton described the implications with excitement: “You know, wow, trout 70 miles away can affect how many elk calves there are. It is just kind of crazy.”

The remaining missing elk calves may be due to drought (which reduces the available forage), increased grizzly bear populations, and wolf predation. Although a shift in grizzly bear diet does not entirely explain the observed decline in elk calves, it is playing a role.

In April of 2013, Middleton published his research, adding elk to the list of species affected by the lake trout invasion. Meanwhile, contract fishermen were gearing up for yet another season of lake trout removal on Yellowstone Lake, as they had been doing for the past four years.

The ice on Yellowstone Lake typically goes out in late May, and contract fishing operations start as soon as the water is open. Three fishing boats with four fishermen each set out from shore at dawn. The boats are equipped with hydraulic lifts to raise miles of gillnet that have been set in the lake overnight. As the fishermen draw the nets out of the water, sun flashes off slabs of silver—a good haul. The fishermen grasp the frigid, slime-covered fish and remove them from the nets. This is not your typical contract fishing operation—these fishermen are in the heart of the nation’s first National Park, and these fish will never see a dinner plate. Instead, their carcasses are destined for the bottom of Yellowstone Lake.

“Part of the Park Service mission is to conserve natural resources, and conserving the Yellowstone cutthroat population within Yellowstone Lake is a huge portion of our natural resources, especially in the fisheries,” explains Patricia Bigelow, fisheries biologist for Yellowstone National Park who has been part of the lake trout control program on Yellowstone Lake for the past fifteen years.

“The problem is the lake trout predation, so if you want to help the cutthroat trout population, *that* is what you need to address,” Bigelow continues, “The goal is to suppress the lake trout population to the point that the cutthroat population can rebound.”

Yellowstone cutthroat trout, named for the red gashes of color slicing underneath their jaws, are highly valued fish. Anglers come from all over the world to fish for this black spotted, golden-red trout that can only be found in the Greater Yellowstone Ecosystem. Hundreds of thousands of Yellowstone National Park visitors once watched from Fishing Bridge on the Yellowstone River as teams of spawning trout jockeyed for position. And as researchers have shown, cutthroat trout are a crucial component of the food web. For these reasons, the park service has gone to war against the lake trout invasion.

In 1995, the Park Service invited a panel of scientists to assess the severity of the situation and advise the control efforts. The panel advised the park to remove lake trout, and the park started the efforts immediately. In 2008, the science panel reconvened and advised the park that it was on the right track, and it needed to do even more to stop the lake trout population growth. In response, the park tried hiring contract fishermen to harvest lake trout, and has continued to increase the control effort every year. By 2012, the park reached control levels recommended by the science panel. Middleton published his research in 2013, providing further fuel for lake trout control efforts and inspiring bumper stickers proclaiming 'Lake Trout Kill Elk.'

Today, the park contracts the Hickey Brothers from Wisconsin to net lake trout every day from ice off until early October, roughly 130 days of fishing every year. On average, the fleet of three boats catches over two thousand fish every day. The fishermen kill the lake trout (if they aren't already dead), count them to monitor the population, pop the air bladder so that the carcass will sink, and dump the fish in the deepest sections of the lake.

The Park, with the help of the Hickey Brothers, has deposited metric tons of fish in Yellowstone Lake in the hopes that these carcasses will keep nutrients in the system. Bob Gresswell, a research biologist who served as chair on both science panels and has been studying Yellowstone cutthroat trout with the park and the US Geological Survey since 1974, says there is no evidence that dumping the fish into Yellowstone Lake is harmful; however, some scientists are concerned that it may be altering the ecosystem in unpredictable ways. Further research is needed to understand the impacts of this "nutrient loading."

Gillnetting removes fish efficiently, but not without consequences, including by-catch of Yellowstone cutthroat trout. The fishermen reduce the amount of by-catch by adjusting the gillnet mesh size. They also focus on areas of the lake that have high densities of lake trout and very few cutthroat trout. The science panel closely monitors by-catch to ensure that it does not exceed levels that could negatively impact the cutthroat trout population. Additionally, if a cutthroat is caught in a net, the fishermen attempt to return it safely to the lake. Even so, over half of the cutthroats caught in the nets will die.

Gillnetting is also expensive. Lake trout control costs the park over a million dollars annually. And if the park ends the program today, all of the progress will be lost. "All of our modeling shows that if you cut back at any point in time, the lake trout will begin to increase again," Gresswell explains, "The suppression of lake trout is something that will always have to occur in Yellowstone Lake. It has to become something that is just part of the working budget of Yellowstone Lake, just like plowing the roads, or cleaning the bathrooms and the campgrounds."

The park is testing cheaper and more efficient ways to control lake trout. One alternative uses large grids of electric wires to zap embryos and emerging fry in lake trout spawning areas. Another uses a mining dredge to suck the embryos out of spawning beds. These alternatives show promise by eliminating by-catch, but they still cannot completely remove lake trout from the system.

Future technologies may provide the solution. Gresswell suggests that "emerging genetic technologies" could help eradicate lake trout from Yellowstone Lake. One solution scientists are developing is to genetically alter male lake trout so that they can only produce male offspring. The idea is that the park would continually stock Yellowstone Lake with these genetically altered males while maintaining gillnetting efforts to control the overall population. With several decades of stocking altered males and gillnetting, the park may be able to eradicate lake trout.

Even without new technology, “There are lots of very positive signs that this suppression activity is beginning to accomplish its goal,” explains Gresswell. Population models suggest that the current level of lake trout harvesting is working. Bigelow states that “it is really exciting that population modeling is showing a decline in the lake trout population overall,” and Gresswell is hopeful that “we should see a relatively rapid, within decades, resurgence of cutthroat trout.”

When irresponsible fishermen introduced lake trout in Yellowstone Lake, they could never imagine the consequences of their actions. Over thirty years later, the lake trout effect is still rippling through the ecosystem in surprising ways. “These cutthroat trout are not just important because they’re native fish,” Middleton said, “they are important because they are at the heart of a … web of interactions that reaches all the way to elk in the outskirts of the Greater Yellowstone Ecosystem that are economically, recreationally, and culturally immensely valuable.” But even with cutthroat trout rebounding, this web of interactions may never be the same again.

Bringing cutthroats back to historic levels would be a huge accomplishment for the park. But whether or not the resurgence of cutthroats will restore the ecosystem is uncertain. “We can’t go around complacently thinking that we have restored Yellowstone. We are not going back to a baseline; we are not fixing it to where it was. We are all going somewhere new,” explained Middleton, “And that’s as sad as it is exhilarating.”

Charlie Reinertsen, *Western Confluence* Editorial Fellow