Stewardship and management of freshwater ecosystems – from Leopold's land ethic to a freshwater ethic

Viewpoint Article for Aquatic Conservation

Steven J. Cooke[1,*], Abigail J. Lynch[2], John J. Piccolo[3], Julian D. Olden[4], Andrea J. Reid[1] and Steve J. Ormerod[5]

[1]Fish Ecology and Conservation Physiology Laboratory, Department of Biology and Institute of Environmental and Interdisciplinary Science, Carleton University, Ottawa, ON, K1S 5B6, Canada

[2]National Climate Adaptation Science Center, United States Geological Survey, Reston, VA, 20192, USA

[3]Department of Environmental and Life Sciences, Karlstad University, Karlstad, 651 88, Sweden

[4]School of Aquatic and Fishery Sciences, University of Washington, Seattle, WA, 98105, USA

[5]Water Research Institute, School of Biosciences, Cardiff University, Cardiff, CF10 3AX, UK

*Correspondence author: Steven.Cooke@carleton.ca

Abstract

1. In 1949, Aldo Leopold formalized the concept of the "land ethic" which became a foundational and transformational way of thinking about natural resource management, biodiversity conservation, and stewardship in terrestrial systems. Yet, the land ethic has inherent linkages to aquatic ecosystems, and Leopold himself conducted research on rivers and lakes while freshwater ecosystems figured widely in his writing.
2. Here, we reflect on the land ethic and other aspects of Leopold's scholarship to identify key messages that provide insight into the stewardship and management of freshwater ecosystems around the globe today. We also frame what we call the "freshwater ethic" around Leopold's legacy. Although he could not have envisioned the stressors affecting modern aquatic ecosystems, Leopold's core principles remain salient. These apply not only to ecosystem protection, but also to the ethics of modern conservation economics, sustainability, and the protection of natural capital in which lakes, rivers, and wetlands now figure prominently.
3. We identify eleven "Aldo-inspired" recommendations for protecting and restoring freshwater ecosystems in the Anthropocene that emanate directly from his writings (e.g., beware of cumulative effects, adopt an ecosystem approach, identify win-win-win scenarios, wild waters are irreplaceable, strive for freshwater optimism).
4. In an epoch where links between people and nature are becoming more explicit in environmental management, policy, and governance, we suggest that Aldo Leopold's work illustrates how inspirational, seminal thinkers have offered leadership in this domain. We contend that today there is still much that can be learned (especially by the next generation of environmental practitioners) from Leopold to ensure effective stewardship of our aquatic ecosystems to maintain and restore aquatic biodiversity and the ecosystem services that derive from healthy streams, rivers, lakes, wetlands, and groundwater.
5. We submit the adoption of a freshwater ethic in parallel to the land ethic will enhance stewardship of the world's increasingly threatened fresh waters by raising the profile of the plight of freshwaters and identifying enduring actions that if embraced will contribute to restoring freshwater biodiversity.

Key Words: Aldo Leopold; Aquatic; Conservation; Land Ethic; Stewardship

Introduction

Aldo Leopold's *A Sand County Almanac* (Leopold 1949) is considered to be among the most influential books ever written for those interested or involved in natural resource management – whether concerned members of the public or environmental professionals. The book's final essay, titled "The land ethic," is an environmental clarion call: it defines a moral responsibility to care for the natural world (Callicott 1987). In many ways, the land ethic is the enduring lodestone of Leopold's conservation philosophy that has resonated for nearly three-quarters of a century (Norton 1988; Newton 2006; Callicott 2013). *A Sand County Almanac* is, still today, required reading for many natural resource and environmental management programs in North America and beyond.

In the classroom and other fora, scholars (largely philosophers and ethicists, but also ecologists and economists) have deconstructed and interpreted Leopold's land ethic in diverse ways (including critiques; e.g., Heffernan 1982) and attempted to identify what he might have posited as the principles for "success" (Callicott et al. 2009; Norton 2011). There is considerable scope for interpreting, and re-interpreting, the land ethic in ways that are as relevant to contemporary conservation scientists and natural resource practitioners anywhere in the world as it was to Leopold in rural Wisconsin in the first half of the twentieth century. For example, Leopold's early discussions in some ways relate directly to key concepts today such as ecosystem resilience (Walker 1995), ecosystem integrity (Karr 1992), ecosystem restoration (Hobbs and Harris 2001) and recovery (Kelly and Harwell 1990), and land economics (Vaughn 1999).

By using the term "land," the "land ethic," is often misinterpreted to only be a terrestrial philosophy. Yet, Leopold's intent, undoubtedly, included both the water and the living inhabitants of streams, rivers, lakes, and wetlands – in much the same way that many Indigenous peoples around the world use "land" in an all-encompassing sense. Leopold states that "The land ethic simply enlarges the boundaries of the community to include soils, waters, plants, and animals, or collectively: the land" (Leopold 1949). To him, "land" is, in the current ecological lexicon, an ecosystem in which people and other organisms live. Nonetheless, the apparent terrestrial connotations have long stuck to these concepts such that only a handful of freshwater scientists (such as Isaac Schlosser, Gene Helfman, Richard Merritt, and Brian Moss), have mused about the land ethic while drawing connections between their aquatic work and that of Leopold (see Schlosser [1991] for his treatment of stream fish ecology at a landscape scale, Helfman [2007] for discussion of how Leopoldian thinking about the conservation fish biodiversity, and Strand and Merritt [1999] for an exploration of the effects of grazing on riparian and

stream ecosystems, for excellent examples). The late Brian Moss (1943-2016) would often cite Aldo Leopold in his public lectures, also prefacing 'The Ecology of Freshwaters' (Moss, 2018) with his words. Most recently, Pister (2010), Piccolo (2012, 2017), and Piccolo et al. (2017), have heightened awareness of the relevance of the land ethic for freshwater scientists. Even the Aldo Leopold Foundation has featured freshwater content relevant to conservation on their website (see https://www.aldoleopold.org/post/7-articles-read-world-water-day/).

Despite these recent perspectives, to our knowledge, there has been no attempt to consider how the land ethic and other aspects of Leopold's thinking interface with challenges facing contemporary scientists and practitioners working on freshwater ecosystem management, conservation, and restoration. This is somewhat surprising given the manifold threats that face freshwater biodiversity (Dudgeon et al. 2006; Harrison et al. 2018; Reid et al. 2019) and the numerous ecosystem services provided by healthy and productive aquatic ecosystems (Lynch et al. 2016; Kuehne et al. 2017). The concept of stewardship is one that certainly resonates within the freshwater conservation community (Fedler et al. 2001; Knuth and Siemer 2004) and there are thus opportunities for Leopold to inform the development of a "freshwater ethic."

For the first time, we provide a comprehensive "freshwater" perspective on the land ethic (but see Auster et al., 2009 for a marine perspective). We acknowledge the extensive writings of various scholars (especially J.B. Callicott) on Leopold that adopt a largely philosophical approach; here we adopt a pragmatic and practical focus on identifying how simple lessons from Leopold can contribute to our contemporary stewardship and conservation actions. Specifically, we reflect on the land ethic and other aspects of Leopold's scholarship to identify key messages that are relevant to inform the stewardship of freshwater ecosystems around the globe. We provide an overview of the direct and indirect links between Leopold and freshwater ecosystems, and consider how the core underpinnings of the land ethic could be applied to freshwater ecosystems. Within the Anthropocene, we recognize an urgency to engage our global citizenry to tackle complex problems; to that end, we conclude by identifying eleven Aldo-inspired recommendations we consider essential for a robust ethic for freshwater ecosystems, today and in the future. Throughout, we also recognize that the world has changed and that there are instances where Leopold's thinking holds less relevance to people today and may not be directly transferable without careful consideration of gender, racial, multiculturalism, and class concerns. We also acknowledge that there are instances where we take liberties to extend our interpretation of Leopold's thinking perhaps beyond his initial intentions. Leopold was not omniscient so it is not

unreasonable to reinterpret his writings through the lens of today. As noted above, this is not intended to be a philosophical treatment but rather a practical paper that extends Leopold's idea more explicitly to the freshwater realm given our collective belief that there is benefit from doing so. Although many would argue that Leopold's writings are timeless, it is our perspective that successive generations of learners and environmental practitioners may be losing touch with the land ethic such that this paper also serves as an accessible way to demonstrate relevance of Leopold to the practitioners of today and tomorrow.

We present the "freshwater ethic" as another way to reframe discussions about what is needed to conserve and restore freshwater biodiversity given its dire state (Reid et al. 2019). Our intention is not to draw attention from the land ethic given the inherent connections between people, land, and water. But, we do see value in thinking explicitly about how Leopold's ideas relate to freshwater issues of today. Tickner et al. (2020) developed an emergency action plan to restore freshwater biodiversity which demands rethinking how we protect and manage freshwater resources. Freshwater needs and deserves the attention of the public and decision makers and that is unlikely to happen without increasing awareness. We accept that the freshwater ethic is embedded within the broader land ethic concept but have highlighted this construct in the hope that it helps address many of the pressing issues that are leading to the loss of freshwater biodiversity. It is our hope that by explicitly adopting a freshwater ethic we will be able to generate the public and political will needed to restore freshwater biodiversity.

Aldo and Aquatics

Leopold was aware of the direct links between land and water – both as a natural resource practitioner and an avid angler (see Figure 1 for photos of Leopold engaging in work and play on waters of North America). Some later aquatic scholars such as Noel Hynes further elaborated on the connection between "the stream and its valley" (including riparia, upland areas and groundwater; Hynes 1975) in a more nuanced and sophisticated manner. Nonetheless, Leopold was explicit about such connections in a simplistic way, emphasized by his journal entries during fishing trips (especially in the southwest; see Leopold 1953). His writings about the American Southwest made clear references to the effects of erosion and silt deposition on fluvial systems as a result of poor range management (Leopold 1946). His colorful descriptions of time spent on the banks of the Rio Gavilan illustrated the ways in which a

pristine catchment (one with ecological integrity) functioned. He reasoned that slow water runoff (as a result of intact land cover) regulated erosion and supported healthy stream habitat for native trout (Forbes 2004). Aldo's son, Luna Leopold, who often accompanied him on fishing and camping trips and who edited *A Sand County Almanac* for publication after his father's untimely death, went on to become a prominent fluvial geomorphologist, writing extensively about water management (Leopold & Wolman 1960; Dunne & Leopold 1978). He wrote *Water—A Primer*, a book arriving after the passage of the Clean Water Act in 1972, that served as an accessible guide for a generation attempting to navigate the complex intersection of environmental science and government bureaucracy. Another of Aldo's sons, A. Starker Leopold, went on to found the University of California, Berkeley - Sagehen Creek experimental station in California's Sierra Nevada Mountains. It was at Sagehen Creek that the first evidence began to accumulate to support wild trout management (Behnke, 2002). Among Starker's students was E. Phil Pister, lifelong fish conservationist, founder of the Desert Fishes Council, and among the leaders of the successful fight before the United States (U.S.) Supreme Court to save the desert pupfish from extinction (see Callicott 2017). To be clear, the fact that Leopold's sons had careers in aquatic science does not establish an inherent link between the Leopoldian land ethic and the aquatic ethic we discuss here, but it is nonetheless interesting history and speaks to his broader legacy.

Aldo, himself, spent much of his career in the U.S.D.A. Forest Service which offered himan opportunity to consider the management of vast tracts of land (especially wilderness) criss-crossed with streams and rivers and dotted with ponds and lakes (see Leopold 1925). As such, most of his musings about wilderness and land management are equally relevant to the waters that traverse or are contained within public lands. In fact, some of the large wilderness spaces that were preserved by the Forest Service contain some of the longest-standing aquatic protected areas. The axiom that "we all live downstream" was apparent to Leopold (1941) and is captured in a quote from one of his unpublished essays (see Leopold 1999) – "To those who know the speech of hills and rivers straightening a stream is like shipping vagrants—a very successful method of passing trouble from one place to the next. It solves nothing in any collective sense." This axiom has since become the foundation for catchment-scale freshwater protected area implementation (e.g., Saunders et al. 2002; Bower et al. 2014) as well as catchment restoration (Williams et al. 1997), both important aspects of the freshwater conservation toolbox.

Although Leopold never explicitly wrote about a "water ethic," "aquatic ethic," or "freshwater ethic," a recent reflection by Lutz Warren (2010) explores the concept by providing a comprehensive

analysis of some his early fisheries writings. For example, in his early days, Leopold created a guidebook for the management of wildlife and fish in the southwest (Leopold 1915) which was one of the first such formal frameworks in resource management. Leopold also became an early commentator on wilderness fish stocking and provided the foundation upon which the U.S. Fish and Wildlife Service based their stocking (see Lutz Warren 2010). In 1918, he published a paper in the *Transactions of the American Fisheries Society* on the "mixing of trout in western waters" (Leopold 1918). He concluded that paper with the rather direct statement "restock with the best adapted species, the native species always preferred" which suggests an appreciation for the role of local adaptation. The idea of trying to think about the relationship between fish production and the environment later became the focus of entire research programs by notable scholars like Fred Fry (Fry 1947) and Rolly Brett (Brett 1971). Pister (2001) provides a historical treatment of wilderness fish stocking and suggests that good ethical practice translates into good biological practice, basing some of his perspectives on the writings of Leopold.

Yet, paradoxically, in some of his other writings and correspondence, Leopold also advocated for stocking non-native species (summarized well in Simberloff 2012) that do not align with current considerations of invasive species. He went on to suggest that "an empty (i.e., fishless) water is an idle resource" (Leopold 2015, pg. 235). Leopold argued that if a lake is fishless because of a severe winterkill event or fisheries collapse then such stocking may be merited, but fishless lakes serve as important habitats for other aquatic organisms such as amphibians (Knapp et al. 2001; Pilliod and Peterson 2001). Some scholars have considered the ethical aspects of invasive species control in the Laurentian Great Lakes using Leopold's framework (Sanford and Uglietta 2010). Leopold had a particular disdain for introduced common carp (*Cyprinus carpio*) but, at that time, there was insufficient research available for him to understand the mechanism by which carp influence freshwater ecosystems (see Simberloff 2012). Given how contentious the topics of fish stocking (especially in wilderness areas) and invasive species have now become (Cucherousset and Olden 2011), and with a much greater evidence base than in Leopold's time (recognizing that his thinking was not static and evolved), it is not surprising that not all of his thinking about freshwater ecosystems was aligned with our current ecological understanding. Nonetheless, he initiated conversations and avenues of inquiry that continue today.

Aldo Leopold's Enduring Relevance

There can be no doubt that the world has changed substantially in the 70 years since the release of *A Sand County Almanac*, and there is a pertinent question about whether Aldo Leopold's worldview stills has currency. His formative and active years straddled two major World Wars, the presidency of two

Roosevelts, the Progressive Era, the Great Depression, and the New Deal, during which the societal context was one of accelerating industrialisation, urbanisation, resource exploitation to power growing economies, and political reform that challenged failures at home and abroad. Against this backdrop, Leopold's commitment to 'wilderness preservation' is understandable. Indigenous perspectives, of which Leopold seems to have been largely unaware, typically do not separate people from nature. Thus, there is ongoing debate regarding what is meant by "wilderness" (Suchet 2002; Sacre et al. 2019) and even about the viability of the very concept of wilderness (Callicott and Nelson 1999). What are now exponentially greater pressures on natural ecosystems from population growth, climate change, and resource use have shifted the modern environmental movement somewhat away from wilderness preservation per se (note – the concept of no take protected areas are consistent with wilderness preservation) to Leopold's primary concern in his Wisconsin years—achieving a harmony between people and land. These stressors impinge particularly on the management of natural resources, on biodiversity conservation, and on socio-economics of land-use decisions whose downstream consequences for fresh waters are large and accelerating (Harrison et al. 2018; Reid et al. 2019). In the modern world, the need to protect ecosystems for their economic value, their natural capital, and their role in human life support have become important adjuncts to the ethical arguments for conservation: for resources as important as fresh waters, these needs are represented clearly in the ecosystem services paradigm (Ormerod 2014; but see Dudgeon 2014 for arguments for intrinsic value of aquatic biodiversity). Yet in Leopold, we find already the search for a new 'conservation economics' that valued ecosystem integrity, resilience, and resource use that operated within natural constraints and protected natural capital:

"The thing to be encouraged is the use of private land in such a way as to combine the public and the private interest to the greatest possible degree. If we are going to spend large sums of public money anyhow, why not use it to subsidize desirable combinations in land use, instead of to cure, by purchase, prohibition, or repair, the headache arising from bad ones?" (Leopold, 1934)

This view has surprising relevance today, particularly in Europe, where the case for 'public spending for public benefit' has become a major political issue in the economics of river catchment management. We acknowledge that the concept of "private lands" is a colonial artefact, but private lands remain, nevertheless, a reality with which resource managers and conservationists must deal.

Inspired by the diverse writings of Aldo Leopold, here we used his direct quotes to posit eleven "Aldo-inspired" recommendations for protecting and restoring freshwater ecosystems in the Anthropocene.

We acknowledge that in our attempts to identify ecological theses we have done an inherent disservice to the eloquent and poetic style of Leopold's writings. We encourage all readers of this essay to consult the original writings of Leopold as his style delivers a philosophical yet practical richness that we cannot even aspire to represent here.

Eleven Aldo-Inspired Recommendations for Freshwater Protection and Restoration

i. **Adopt an ecosystem approach:** *"Harmony with land is like harmony with a friend; you cannot cherish his right hand and chop off his left. That is to say, you cannot love game and hate predators; you cannot conserve the waters and waste the ranges; you cannot build the forest and mine the farm. The land is one organism." - Aldo Leopold (1949)*

Leopold's land ethic was founded squarely upon his eco-evolutionary understanding of nature; he was a forester, game manager, and ecologist by trade. Leopold earned a master's degree from the Yale Forest School, he wrote the first major textbook on game management in the U.S. (i.e., *Game Management*), and he served as President of the Ecological Society of America. He fully understood that ecosystems are built of complex and dynamic interactions of materials and energy and his writings foreshadow the areas of academic study in ecosystem science as well as ecosystem stewardship. Such thinking remains highly relevant today as we move towards an ecosystem approach to the management of aquatic systems (Frissell and Bayles 1996) — or better "return to it" to the extent in that Indigenous management based on traditional ecological knowledge (TEK) predated modern conceptions of ecosystem management. An ecosystem approach extends beyond the physical (e.g., time and space) to include the process by which we consider and involve humans as parts of ecosystems and the management process (Long, Charles & Stephenson 2016). Leopold was a contemporary of aquatic ecosystem ecologist Stephen Forbes who was one of the first to recognize the inherent interconnectedness of organisms and their environment (Forbes 1887). It took decades after Leopold's passing before the "harmony" – the interconnections – he thought about so much became fully ingrained in our thinking about resource management (Grumbine 1994). Recently, Langhans et al. (2018) illustrated how an ecosystem approach to management in a freshwater context can increase public acceptance by introducing the consideration of human needs and aspirations into conventionally biodiversity-driven management approaches.

ii. **Manage coupled social-ecological systems:** *"We abuse land because we regard it as a commodity belonging to us. When we see land as a community to which we belong, we may begin to use it with love and respect." - Aldo Leopold (1949)*

Leopold, progressive in his thinking in many respects, was also one of the first to recognize, in an ecological and Western scientific context, that humans are inextricably linked with the ecosystems to which they belong. Additionally, only by explicitly treating these systems as part of our "community" rather than as a "commodity," can these systems be managed sustainably. Leopold's perspective has surely influenced modern ecological theory, including current thinking on social-ecological systems (see Berkes, Colding & Folke 2001; Berkes, Doubleday & Cumming 2012) and coupled human and natural systems (see Liu et al. 2007a), and has undoubtedly permeated into a number of global initiatives, such as the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). Indeed, freshwater fisheries systems may be among the best known coupled systems, with examples of collapse when this dynamic is not respected and opportunities for effective adaptive management when it is (Lynch and Liu 2014). Just north of the Leopold family's shack (in Wisconsin), the U.S. National Science Foundation has designated a Long-term Ecological Research unit in the North Temperate Lakes to examine the feedbacks between human use impacts between agriculture and tourism (Liu et al. 2007b). The dynamics of aquatic coupled social-ecological systems are complex but exploratory modeling can help provide management with bounding constraints on strategies that are feasible and resilient to uncertainty (Carpenter and Gunderson 2001). Our management failings often stem from our failure to recognize important characteristics of the coupled systems, reciprocal effects, feedbacks, thresholds, surprises, traps, or legacy effects (Liu et al. 2007a). Likewise, our management successes are often rooted in an acknowledgement of the complexities human-aquatic system interactions, a willingness to reassess approaches, and adapt to changing conditions. Through Leopold's "community," we will best be able to manage our freshwater resources sustainably in a changing world.

iii. **Acknowledge the limits to human dominance:** *"The government tells us we need flood control and comes to straighten the creek in our pasture. The engineer on the job tells us the creek is now able to carry off more flood water, but in the process we have lost our old willows where the owl hooted on a winter night and under which the cows switched flies in the noon shade. We lost the little marshy spot where our fringed gentians bloomed." - Aldo Leopold (1953)*

Naturally flowing rivers are among the most dynamic ecosystems on Earth; consequently, many rivers have been heavily modified to control streamflows to meet human needs while dampening or

eliminating normal floods and droughts (Grill et al. 2019). But as Leopold astutely recognizes, there are clear limits to the resilience of freshwater ecosystems to human use (see Folke 2003). Human control of river flows is now nearly ubiquitous, with millions of dams worldwide that holdback nearly one-tenth of the water stored in natural lakes or about one-sixth of the total annual river flow into oceans. Despite providing many societal benefits, it is well recognized that river regulation has also caused considerable ecological damage and the loss of important ecosystem services valued by society. Now more so than ever, societies are grappling with the need to supply reliable and affordable water to growing populations, while at the same time not degrading freshwater ecosystems nor disrupting their important ecosystem goods and services (Arthington et al. 2018). Leopold's thoughts remind us that although humans will continue to depend on freshwater ecosystems for water, food, and energy security, we must overcome the past over-exploitative tendencies of the dominant majority to ensure that the "fringed gentians" can continue to bloom.

iv. **Account for cumulative effects of multiple threats:** *"Man's invention of tools has enabled him to make changes of unprecedented violence, rapidity and scope." - Aldo Leopold (1949)*

Humans are the dominant force on planet Earth (Vitousek et al. 1998). Leopold already recognized that at a time when the word "Anthropocene" had yet to be created. However, Leopold clearly acknowledged that the land (often discussed in the context of soil) suffered from many different ills. Often colloquially termed the "death by a thousand cuts," cumulative effects (i.e., the accumulation of multiple human-induced threats over time and space; Craig et al. 2017) are very real and represent a major challenge today just as when Leopold mused about them many decades ago. The threats are truly obscured (at least to the naked eye) – such as microplastics, nanomaterials, and pharmaceuticals (see Reid et al. 2019) or simply additive impacts, yet another stream crossing, another dam, and another development, where collectively those threats compound to yield major problems. In certain cases, it is only when threats combine in complex ways (e.g., synergistically; see Folt et al. 1999) that their full suite of negative consequences are realized which creates challenges for assessing and managing threats to fresh water ecosystems. Cumulative effects are inherently difficult to study and manage although it is possible to do so, and several frameworks exist for doing so (Seitz et al. 2011, Craig et al. 2017). In the face of cumulative effects, somewhat conservative and precautionary management approaches are needed that focus on maintaining ecosystem resilience (Duinker and Greig 2006; Gavaris 2009) and incorporate cumulative effects into risk assessments (Scrimgeour et al. 2008). Additional effort is needed to ensure that multiple threats are fully integrated into contemporary freshwater and

catchment assessment, management, and governance to ensure that they are understood and mitigated.

v. **Address underlying causes not symptoms of problems:** *"The practices we now call conservation are, to a large extent, local alleviations of biotic pain. They are necessary, but they must not be confused with cures." - Aldo Leopold (1949)*

Leopold recognized that there was a tendency to focus on treating symptoms of environmental problems rather than addressing the underlying cause; it is difficult to argue that we do not succumb to the same pitfalls to this day (Lindenmayer and Hunter 2010). It is still the norm, particularly in industrialized nations, to focus on "band-aid" solutions (e.g., Vörösmarty et al. 2010). In the context of catchments where surface water moves from the land to the stream, and from the headwaters downstream, failing to address the underlying problem ensures that the stressor will persist and, at some point, it is likely that interventions being used to treat the "symptom" will fail. In one successful cause-focused approach, a project focused on restoration of surface-groundwater interactions in rivers explicitly set out to address and alleviate the causes of degradation (Kasahara et al. 2009). Similarly, the "urban stream syndrome" very intentionally recognizes the need for cures rather than treating the symptoms (Walsh et al. 2005). Moving forward, there is considerable scope to heed the early advice from Leopold and recognize that resources devoted to addressing symptoms of a problem represent short-sighted investments that "must not be confused with cures" and will fail to ensure long-term success. Further yet, this philosophy must extend to understanding the indirect causes – including economic growth and overconsumption by dominant human societies – and to recognizing that ultimate solutions will require social, political, economic and legal change.

vi. **Acting even in the absence of complete understanding:** *"No matter how intently one studies the hundred little dramas of the woods and meadows, one can never learn all the salient facts about any one of them." - Aldo Leopold (1949)*

A freshwater biodiversity crisis is upon us (Harrison et al. 2018), and environmental practitioners must apply effective interventions as rapidly as possible. Yet, rarely is there sufficient knowledge to act with the certainty that one would wish. Uncertainty is a reality within science and especially apparent in the realm of ecology (Regan et al. 2002) and is further amplified by the "opaqueness" of aquatic systems. Some have argued that we can study a population or species to extirpation or extinction, respectively (Lawton 1993), such that always asking for "more" science is simply not realistic. On a daily basis,

resource managers and practitioners are required to make decisions regarding conservation and management actions – some of which may not in fact be even based on the best available scientific evidence (Pullin et al. 2004). There is now a movement towards evidence-based decision making (Webb et al. 2017) including in the aquatic realm (Cooke et al. 2017) where systematic reviews are used as the "gold standard" of evidence synthesis (Sutherland et al. 2004) – an activity we support whole-heartedly. Yet, systematic reviews have not been conducted for every intervention and even where systematic reviews are completed, it is not uncommon to conclude that the evidence base is insufficient or weak such that it is impossible to draw any conclusions regarding the effectiveness of interventions (see www.conservationevidence.com and www.environmentalevidence.org for related resources). So, does that mean that resource managers should not manage, and that decision-makers should not decide? As noted by Leopold, the only real certainty is uncertainty. At some point one must act. This is not a plea for taking short cuts or ignoring evidence; it is rather an embrace of a pragmatic perspective that requires decisions to be made with imperfect evidence, without "all the salient facts." A precautionary approach can be adopted in the absence of evidence (Cooney 2004).

vii. **Identify win-win-win scenarios:** *"Cease being intimidated by the argument that a right action is impossible because it does not yield maximum profits, or that a wrong action is to be condoned because it pays." - Aldo Leopold (written 1947; published 1991)*

Leopold lamented economic excuses for failing to act in the best interest of the environment. In a world that is "profit" driven, Leopold asks us to turn this argument on its head and look for solutions that can have economic *and* ecological rewards. These "win-win" scenarios are cases where strategic action can benefit all sectors involved. The most successful cases employ innovative approaches to minimize trade-offs between benefits to one party and costs to another. Ecosystem approaches to inland fisheries management are generally touted as the best case "win-win-win" scenario – as a "win" for the fish by sustaining ecosystem productivity, a "win" for the fisheries because the fisheries can flourish, and a "win" for other water resource users with cleaner water (Beard et al. 2011). Clean water is a common linkage for "win-wins" in aquatic systems because clean water provides benefits to humans and often restores ecosystem function for aquatic organisms (e.g., Carson and Mitchell 1993). Additional examples of "win-win" solutions for inland fish and fisheries are provided by Lynch et al. (2016). In the Anthropocene, we extend Leopold's vision to also embrace and strengthen conservation partnerships that include public and private land and rights holders (Dombeck et al. 2003). Leopold frames this "argument" as a moral dilemma and he uses it as a call to arms. While this can still be (and often is) a

motivation for aquatic ecologists, we are often better served by a willingness to work collaboratively with other sectors and groups to achieve desired ends. "Win-win-win" is a winning strategy, in part, because it is cooperative and broadly beneficial. Increasing public awareness (i.e., voters, shareholders) about the importance of achieving win-win-win scenarios can be used as 'leverage' to further encourage adoption of compromises in resource development. With more authentic partnerships and cross-sectorial co-generation of knowledge, there will undoubtedly be greater buy-in and, consequently, better pay-out.

viii. **Wild waters are irreplaceable:** *"Perhaps our grandsons, having never seen a wild river, will never miss the chance to set a canoe in one" - Aldo Leopold (1949)*

Musing that a wild river lost will not be missed, Leopold ironically highlights that, indeed, it will be a major loss to future generations. Protected area designation remains among the most relevant of all of Leopold's insights – today, the Convention for Biological Diversity targets protection of 17% terrestrial and inland water habitats and 10% marine habitats (Secretariat of the Convention on Biological Diversity 2010). Furthermore, there is growing scientific evidence that we will need to protect up to 50% to ensure sustainable flows of ecosystem services and avert widespread ecosystem collapse. Yet, establishment of marine and freshwater protected areas lags behind terrestrial habitat protection (Hermoso et al. 2016; Loury et al. 2018). Recently, a group of leading conservation biologists have warned that "global conservation policy must stop the disappearance of Earth's few intact ecosystems" (Watson et al. 2018). The value of wilderness for freshwater habitats, for example, can be seen from the tremendous ecosystem services provided by free-flowing rivers (Auerbach et al. 2014), including "the chance to set a canoe" in them and Alaska's sustainable wild salmon fisheries, widely recognized as a model for sustainable fisheries management (Cline, Schindler & Hilborn 2017).

ix. **Relationships with nature are essential:** *"Like winds and sunsets, wild things were taken for granted until progress began to do away with them." - Aldo Leopold (1949)*

As human society successively replace wild places (e.g., forests, fresh waters) with infrastructure and development linked to urbanisation and resource extraction (Foley et al. 2005), we are becoming increasingly disconnected from nature (Kareiva 2008). This "progress" is particularly apparent among youth who are spending an increasing amount of time in virtual realities and contexts, and less and less time outdoors – the so-called "extinction of experience" (Pergams and Zaradic 2006; Soga and Gaston 2016). Given that time spent in nature is fundamental to our connection to it (Kals et al. 1999) – and that

today's youth represents tomorrow's stewards of nature – it is imperative that we prioritize protecting the connection between people, particularly children, and nature *now* (Soga and Gaston 2016). As emphasized elsewhere in this article, fresh waters are in an increasingly perilous state and establishing strong connections between humans and freshwater systems represents a real opportunity for instilling Leopold's land (and aquatic) ethic in the next generation before "progress…[does] away with them." A very positive signal in terms of human relationships with nature is the recent focus on relational values (RV) by IPBES (Pascual et al. 2017). The RV concept (i.e., values that arise from a relationship with nature which may encompass a sense of place, well-being, and cultural, community, or personal identities; Chan, Gould & Pascual 2018) has the potential to supplement the traditional ecosystem services approach by acknowledging the meaningfulness of human-nature relationships in providing for a good life.

x. **Embrace freshwater optimism:** *"We shall never achieve harmony with the land, anymore than we shall achieve absolute justice or liberty for people. In these higher aspirations the important thing is not to achieve but to strive." - Aldo Leopold (written 1938; published 1953)*

Leopold recognized that human development was a necessity and conflicts between human and nature would continue. Yet, he also struck an optimistic, yet pragmatic tone which is particularly striking today as many seek to define what it means to achieve a "good" Anthropocene (Dalby 2016; Bennett et al. 2016). To be clear, Leopold was unsure if humanity could change its ways but he certainly ceded that we must try. And to try, one must hold some level of optimism. Indeed, there is a growing recognition for the need to develop alternatives to the "sky is falling" narrative (Beever 2000). The concepts of hope and optimism have emerged in recent decades (Swaisgood and Sheppard 2010; Garnett and Lindenmayer 2011) more broadly within conservation science but are particularly important for aquatic systems. For example, the #oceanoptimism movement (see Kelsey 2016) has seen investments in understanding the role of public perceptions in framing ocean conservation issues (Jefferson et al. 2015). In the freshwater realm, alarm bells continue to ring regarding the grim state of biodiversity and expanding threats (e.g., Harrison et al. 2018; Reid et al. 2019), yet there are also reasons to be optimistic (Geist 2015) and efforts to better engage the public as allies (Cooke et al. 2013). Embracing the optimism and tenacity of Leopold as "higher aspirations" will be useful for further advancing and realizing incremental progress in freshwater conservation. However, this perspective must also be

balanced with Leopold's inherently more pessimistic thinking. Indeed, that tension between optimisms and pessimism remains today.

xi. **Appreciating the diverse values of freshwater biodiversity:** *"Our ability to perceive quality in nature begins, as in art, with the pretty. It expands through successive stages of the beautiful to values as yet uncaptured by language." - Aldo Leopold (1949)*

Freshwater biodiversity provides a broad variety of valuable goods and services for human societies, many of them irreplaceable. Yet, as Leopold suggests, measuring the value of biodiversity as simply the monetary sum of derived goods and services is inappropriate, because intangible factors such as beauty, life-fulfilling values, and spirituality are of extreme importance. The appreciation of the various values of biodiversity for humankind – ranging from utilitarian to ethical – is essential (Kellert 1997). For instance, aesthetic values (i.e., physical appeal and beauty) of freshwater environments have been long unappreciated by many because they are unseen. The vast majority of their inhabitants (e.g., fish, invertebrates) remain "out of sight, and largely out of mind," (e.g., turbid water, thick macrophyte cover, stygofauna in groundwater) and there is generally an absence of megafauna (but see Carrizo et al. 2017) that is so common in the marine realm; this lack of public awareness of freshwater life may ultimately limit freshwater conservation as a popular cause, or movement (Monroe et al. 2009; Boon and Baxter 2016). Leopold argues that direct experience of nature's beauty is priceless, and here we extend this argument to images and visual media. Photographs and videos can play a critical role in visually connecting freshwater ecosystems to their would-be stewards. Images are capable of conveying information and evoking emotion at a glance, and are generally more intuitive, more quickly assimilated, and often more memorable than verbal description (Monroe et al. 2009). Looking ahead, better appreciation of the diverse values of freshwater biodiversity "as yet uncaptured by language" will undoubtedly contribute to a more inclusive freshwater ethic.

Synthesis and Conclusion

We are now in an epoch when links between people and nature are increasingly explicit in environmental management, policy, and governance. Concepts such as natural capital, ecosystem services, nature's contributions to people, and natural resource management are prominent drivers of decisions in weighing environmental exploitation with environmental protection. There is value, then, in considering the contributions made by individuals who have shaped current philosophical positions on these topics through their inspiration, seminal thoughts, and leadership. Among these figures, Aldo

Leopold continues to stand out. A sign of the universal and timeless appeal of Leopold's ethic is Rozzi's (2015, 2018) biocultural conservation ethic which draws explicitly on Leopold and recognizes the widespread traditions among Indigenous peoples around the world of human cohabitation with and indivisibility from nature - precisely as Leopold wrote : "that men are only fellow voyagers with other creatures in the odyssey of evolution." (Leopold 1949, quoted in Rozzi 2018).

Yet, much has changed. For example, we are now in an era of attempted reconciliation between settlers and Indigenous peoples in North America, where the dominant majority is beginning to awaken to the long-standing injustices borne by Indigenous peoples of these lands and waters at the hands of settler colonists (Adams and Mulligan 2003). Early (Leopold era) resource management and conservation failed to adequately or respectfully include Indigenous perspectives and rights. Recent studies have revealed that imperiled species fare as well on Indigenous lands as they do in formal protected areas (Schuster et al. 2019) emphasizing that there is still much to learn from the traditional ecological knowledge of Indigenous peoples. Additionally, we now acknowledge other elements of social awareness (e.g., gender, sexual orientation, race) that are absent in a perspective that only recognizes "grandsons" as beneficiaries. This is to say that although we still have much to learn from Leopold, there are other voices, knowledges, and perspectives that should be embraced by conversations about contemporary and future natural resource management – something that we have only recently recognized and begun to do (Gould et al. 2018). Although beyond the scope of this article, they are also important sources in framing conservation today – reflecting a more inclusive perspective than those presented in Leopold's writings (see Tallis and Lubchenco 2014; Green et al. 2015; Gould et al. 2018).

Here, we considered how Aldo Leopold's "land ethic" is relevant to the conservation, management, and stewardship of freshwater ecosystems – or what we term – the "freshwater ethic." What is remarkable is that the messages that we drew from some of the most important and beloved quotes from Leopold mirror those emerging from contemporary discussions about what is needed to achieve healthy and productive freshwater ecosystems (e.g., Lapointe et al. 2014). This is perhaps not surprising given that Leopold was a holistic thinker (Coufal 2000). Although the "land" ethic has terrestrial connotations, Leopold was intimately aware of the connections between land and water (i.e., catchment) as we have noted above. We contend that Leopold probably deserves more credit for his influence on applied freshwater science (see Table 1 for examples). We also suggest that *A Sand County Almanac* is as relevant to trainees in freshwater science as to those in forestry, wildlife management, conservation science, environmental ethics, and rangeland ecology. More importantly, his writings are also valuable

to members of the public and the diverse stakeholders that interact with the natural world. Leopold was well aware of the fact that humans were both the cause of and the solution to most environmental problems. Wouldn't it be great if A *Sand County Almanac* was as common in the classroom as *A Tale of Two Cities, The Great Gatsby*, *To Kill a Mockingbird*, or *Wuthering Heights* (to name a few)?

Leopold was both wise and visionary, influencing many scholars and contemporary environmental stewards through the paradigms he developed. We, like many others in our field, have been significantly influenced by Leopold's conservation philosophy and hold that "when we see land as a community to which we belong, we may begin to use it with love and respect." Yet, we suspect he would be underwhelmed by the extent to which we have fully embraced what he advocated for so eloquently. Throughout Leopold's writings and our eleven Aldo-inspired recommendations, we see alignment with global conservation initiatives. For example, IPBES places a strong emphasis on the indirect drivers as the ultimate cause and the source of solutions – not unlike the "pains" and "cures" discussed by Leopold (see recommendation v in this paper) and not unlike his repeated critique of treating the more-than-human world as a commodity and limiting conservation motives to the economic sphere (see recommendations ii, viii, and ix in this paper). The bioethical principles celebrated by the "land ethic," notes his son Carl Leopold, can be rapidly altered or destroyed by social dysfunctions such as greed, poverty, and war (Leopold 2004) – ideas that were not explicitly raised by Aldo Leopold. In short, the "freshwater ethic" needs to be updated given changes in worldviews – incorporating diverse perspectives in recognition of the need for a more inclusive approach to conservation and management of natural resources where people of marginalized and colonized communities have an opportunity and a right to participate (Green et al. 2015).

The dystopian future that some envision with the term "Anthropocene" would be such a manifestation of that social dysfunction. To that end, and in the quest for a "good" Anthropocene (Dalby 2016), it will be important to recognize the inherent links between humans and freshwater ecosystems and recognize that many of the solutions will not be about ecology but rather about human behaviour – as individuals and as a collective society. These eleven Aldo-inspired recommendations (recognizing that we may or may not have interpreted them in exactly the same way Leopold intended) should flavour our thinking as we develop effective partnerships, engage the global citizenry, and generate the public and political will necessary to reverse the decline of freshwater biodiversity and maintain the diverse and important ecosystem services generated by freshwater ecosystems. To that end, it is time to embrace a "freshwater ethic."

Acknowledgements

Cooke and Reid are supported by the Natural Sciences and Engineering Research Council of Canada (NSERC), and Cooke is also supported by the Canada Research Chairs Program and Genome Canada. Reid is a citizen of the Nisga'a Nation and her studies are sponsored by the Nisga'a Lisims Government. Cooke, Lynch, and Reid are members of InFish, a professional network to promote global conservation and responsible use of inland fish(infish.org), and Olden and Piccolo are members of the Society for Conservation Biology Freshwater Working Group. We are honoured that Estella Leopold took the time to read this essay and furnish us with comments and encouragement to press forward with the idea. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

ReferencesAdams, W. M., & Mulligan, M. (Eds.). (2003). Decolonizing nature: strategies for conservation in a post-colonial era. Earthscan, London.

Arthington, A. H., Bhaduri, A., Bunn, S. E., Jackson, S. E., Tharme, R. E., Tickner, D., ... & Horne, A. C. (2018). The Brisbane declaration and global action agenda on environmental flows (2018). Frontiers in Environmental Science, 6, 45. doi: 10.3389/fenvs.2018.00045

Auerbach, D. A., Deisenroth, D. B., McShane, R. R., McCluney, K. E. & Poff, N.L. (2014). Beyond the concrete: accounting for ecosystem services from free-flowing rivers. Ecosyst. Serv. 10, 1–5.

Auster, P. J., Fujita, R., Kellert, S. R., Avise, J., Campagna, C., Cuker, B., ... & Di Sciara, G. N. (2009). Developing an ocean ethic: science, utility, aesthetics, self-interest, and different ways of knowing. Conservation Biology, 23(1), 233-235.

Beard, T.D., R. Arlinghaus, D. Bartley, S.J. Cooke, S. de Silva, P. McIntyre and I.G. Cowx. 2011. Ecosystem approach to inland fisheries: research needs and implementation strategies. Biology Letters 7:481-483 Beever, E. (2000). Diversity: The Roles of Optimism in Conservation Biology. Conservation Biology, 14(3), 907-909.

Behnke, R. J. (2002). Trout and salmon of North America. The Free Press, New York. Bennett, E.M., Solan, M., Biggs, R., McPhearson, T., Norström, A.V., Olsson, P., Pereira, L., Peterson, G.D., Raudsepp-Hearne, C., Biermann, F. and Carpenter, S.R., 2016. Bright spots: seeds of a good Anthropocene. Frontiers in Ecology and the Environment, 14(8), pp.441-448.

Berkes, F., Colding, J., and Folke, C. (2001) Linking Social-Ecological Systems. Cambridge: Cambridge University Press.

Berkes, F., Doubleday, N. C., & Cumming, G. S. (2012). Aldo Leopold's land health from a resilience point of view: self-renewal capacity of social–ecological systems. EcoHealth, 9(3), 278-287.

Boon, P.J., and J.M. Baxter. 2016. Aquatic conservation: reflections on the first 25 years. Aquatic Conservation 26: 809–816.

Bower, S. D., Lennox, R. J., & Cooke, S. J. (2014). Is there a role for freshwater protected areas in the conservation of migratory fish? Inland Waters, 5(1), 1-6.

Brett, J.R., 1971. Energetic responses of salmon to temperature. A study of some thermal relations in the physiology and freshwater ecology of sockeye salmon (Oncorhynchus nerkd). American zoologist, 11(1), pp.99-113.

Callicott, J. B. (1987). The conceptual foundations of the land ethic. Technology and values: Essential readings, 438-53.

Callicott, J. B. (2013). Thinking like a planet: The land ethic and the earth ethic. Oxford University Press, Oxford UK

Callicott, J. B. (2017) What good is it anyway? In: Garson J, Plutynski A and Sarkar S, eds. The Routledge Handbook of Philosophy of Biodiversity. Routledge, London, UK: 168–82.

Callicott, J. B & Nelson, M. P. (1999). The Great New Wilderness Debate. Athens: University of Georgia Press.

Callicott, J. B., Grove-Fanning, W., Rowland, J., Baskind, D., French, R. H., & Walker, K. (2009). Was Aldo Leopold a Pragmatist? Rescuing Leopold from the Imagination of Bryan Norton. Environmental Values, 18(4), 453-486.

Carpenter, S. R., & Gunderson, L. H. (2001). Coping with Collapse: Ecological and Social Dynamics in Ecosystem Management: Like flight simulators that train would-be aviators, simple models can be used to evoke people's adaptive, forward-thinking behavior, aimed in this instance at sustainability of human–natural systems. BioScience, 51(6), 451-457.

Carrizo, S.F., Jähnig, S.C., Bremerich, V., Freyhof, J., Harrison, I., He, F., Langhans, S.D., Tockner, K., Zarfl, C. and Darwall, W., 2017. Freshwater megafauna: Flagships for freshwater biodiversity under threat. Bioscience, 67(10), pp.919-927.

Carson, R. T., & Mitchell, R. C. (1993). The value of clean water: the public's willingness to pay for boa table, fishable, and swimmable quality water. Water Resources Research, 29(7), 2445-2454.

Cline, T. J., Schindler, D. E., & Hilborn, R. (2017). Fisheries portfolio diversification and turnover buffer Alaskan fishing communities from abrupt resource and market changes. Nature Communications, 8, 14042.

Cooke, S. J., Lapointe, N. W. R., Martins, E. G., Thiem, J. D., Raby, G. D., Taylor, M. K., ... & Cowx, I. G. (2013). Failure to engage the public in issues related to inland fishes and fisheries: strategies for building public and political will to promote meaningful conservation. Journal of Fish Biology, 83(4), 997-1018.

Cooke, S.J., S. Wesch, L.A. Donaldson, A.D.M. Wilson & N. Haddaway. (2017). A call for evidence-based conservation and management of fisheries and aquatic resources. Fisheries. 42(3): 143-149.

Cooney, R., 2004. The precautionary principle in biodiversity conservation and natural resource management: an issues paper for policy-makers, researchers and practitioners (No. 2). IUCN, Switzerland.

Coufal, J. E. (2000). The land ethic question. Environmental Ethics and Forestry: A Reader, 6, 184.

Craig, L. S., Olden, J. D., Arthington, A. H., Entrekin, S., Hawkins, C. P., Kelly, J. J., ... & Strayer, D. L. (2017). Meeting the challenge of interacting threats in freshwater ecosystems: A call to scientists and managers. Elem Sci Anth, 5.

Cucherousset, J., & Olden, J. D. (2011). Ecological impacts of nonnative freshwater fishes. Fisheries, 36(5), 215-230.

Dalby, S. (2016). Framing the Anthropocene: The good, the bad and the ugly. The Anthropocene Review, 3(1), 33-51.

Dombeck. M., Wood, C.A., & J.E. Williams. (2003). From Conquest to Conservation: Our Public Lands Legacy. Island Press, NY. 232 pp.

Dudgeon, D. 2014. Accept no substitute: biodiversity matters. Aquatic Conservation 24: 435–440

Dudgeon, D., Arthington, A.H., Gessner, M.O., Kawabata, Z.I., Knowler, D.J., Lévêque, C., Naiman, R.J., Prieur-Richard, A.H., Soto, D., Stiassny, M.L. and Sullivan, C.A., 2006. Freshwater biodiversity: importance, threats, status and conservation challenges. Biological reviews, 81(2), pp.163-182.

Duinker, P.N. and Greig, L.A., 2006. The impotence of cumulative effects assessment in Canada: ailments and ideas for redeployment. Environmental management, 37(2), pp.153-161.

Dunne, T., & Leopold, L. B. (1978). Water in environmental planning. Macmillan, New York.

Fedler, A. J., Siemer, W. F., Knuth, B. A., & Matthews, B. E. (2001). Developing Aquatic Resource Stewards. Taproot, 12(4), 9-15.

Foley, J. A., DeFries, R., Asner, G. P., Barford, C., Bonan, G., Carpenter, S. R., ... & Helkowski, J. H. (2005). Global consequences of land use. Science, 309(5734), 570-574.

Folke, C. (2003). Freshwater for resilience: a shift in thinking. Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences, 358(1440), 2027-2036.

Folt, C.L., Chen, C.Y., Moore, M.V. and Burnaford, J., 1999. Synergism and antagonism among multiple stressors. Limnology and oceanography, 44(3part2), pp.864-877.

Forbes, S.A. (1887). The Lake as a Microcosm. Bulletin of the Scientific Association of Peoria, Illinois, pp 77–87.

Forbes, W. (2004). Revisiting Aldo Leopold's" perfect" Land Health: Conservation and Development in Mexico's Rio Gavilan (Doctoral dissertation, University of North Texas).

Frissell, C. A., & Bayles, D. (1996). Ecosystem management and the conservation of aquatic biodiversity and ecological integrity. Journal of the American Water Resources Association, 32(2), 229-240.

Fry, F.E.J., 1947. Effects of the environment on animal activity. Pub. Ontario Fish. Lab. No. 68. U. Toronto Studies, Biol. Ser., 55, pp.1-52.

Garnett, S. and Lindenmayer, D., 2011. Conservation science must engender hope to succeed. Trends in Ecology and Evolution, 26(2), pp.59-59.

Gavaris, S., 2009. Fisheries management planning and support for strategic and tactical decisions in an ecosystem approach context. Fisheries Research, 100(1), pp.6-14.

Geist, J. (2015). Seven steps towards improving freshwater conservation. Aquatic Conservation: Marine and Freshwater Ecosystems, 25(4), 447-453.

Gould, R. K., Phukan, I., Mendoza, M. E., Ardoin, N. M., & Panikkar, B. (2018). Seizing opportunities to diversify conservation. Conservation Letters, 11(4), e12431.

Green, S. J., Armstrong, J., Bogan, M., Darling, E., Kross, S., Rochman, C. M., et al. (2015). Conservation needs diverse values, approaches, and practitioners. Conservation Letters, 8(6), 385-387.

Grill, G., B. Lehner, M. Thieme, B. Geenen, D. Tickner, F. Antonelli, S. Babu, P. Borrelli, L. Cheng, H. Crochetiere, H. Ehalt Macedo, R. Filgueiras, M. Goichot, J. Higgins, Z. Hogan, B. Lip, M. McClain, J.-h. Meng, M. Mulligan, C. Nilsson, J. D. Olden, J. Opperman, P. Petry, C. Reidy Liermann, L. Saenz, S. Salinas-Rodríguez, P. Schelle, R. J. P. Schmitt, J. Snider, F. Tan, K. Tockner, P. H. Valdujo, A. van Soesbergen, & Zarfl, C. (2019). Mapping the world's free-flowing rivers. Nature 569, 215-221.

Grumbine, R. E. (1994). What is ecosystem management? Conservation Biology, 8(1), 27-38.

Harrison, I., Abell, R., Darwall, W., Thieme, M. L., Tickner, D., & Timboe, I. (2018). The freshwater biodiversity crisis. Science, 362(6421), 1369-1369.Harrison, I., Abell, R., Darwall, W., Thieme, M. L., Tickner, D., & Timboe, I. (2018). The freshwater biodiversity crisis. Science, 362(6421), 1369-1369.

Heffernan, J.D., 1982. The land ethic: A critical appraisal. Environmental Ethics, 4(3), pp.235-247.

Helfman, G.S. 2007. Fish Conservation: A Guide to Understanding and Restoring Global Aquatic Biodiversity and Fishery Resources.. Island Press, Washington,
D.C. 584 pages

Hermoso, V., R. Abell, S. Linke and P. Boon. 2016. The role of protected areas for freshwater biodiversity conservation: challenges and opportunities in a rapidly changing world. Aquatic Conservation. 26 (Suppl. 1): 3–11.

Hobbs, R. J., & Harris, J. A. (2001). Restoration ecology: repairing the earth's ecosystems in the new millennium. Restoration ecology, 9(2), 239-246.

Hynes, H. B. N. (1975). The stream and its valley: With 4 figures and 2 tables in the text. Internationale Vereinigung für theoretische und angewandte Limnologie: Verhandlungen, 19(1), 1-15.

Jefferson, R., McKinley, E., Capstick, S., Fletcher, S., Griffin, H., & Milanese, M. (2015). Understanding audiences: making public perceptions research matter to marine conservation. Ocean & Coastal Management, 115, 61-70.

Kals, E., Schumacher, D., & Montada, L. (1999). Emotional affinity toward nature as a motivational basis to protect nature. Environment and Behavior, 31(2), 178-202.
Kareiva, P. (2008). Ominous trends in nature recreation. Proceedings of the National Academy of Sciences, 105(8), 2757-2758.

Karr, J. R. (1992). Ecological integrity: protecting earth's life support systems. Ecosystem health: new goals for environmental management. Island Press, Washington, DC, USA, 223-238.

Kasahara, T., Datry, T., Mutz, M., & Boulton, A. J. (2009). Treating causes not symptoms: restoration of surface–groundwater interactions in rivers. Marine and freshwater research, 60(9), 976-981.

Kellert, S. R. (1997). The value of life: Biological diversity and human society. Island Press, New York.

Kelly, J. R., & Harwell, M. A. (1990). Indicators of ecosystem recovery. Environmental Management, 14(5), 527-545.

Kelsey, E., 2016. The rise of ocean optimism. Hakai Magazine, 8.
https://www.hakaimagazine.com/features/rise-ocean-optimism/

Knapp, R. A., Corn, P. S., & Schindler, D. E. (2001). The introduction of nonnative fish into wilderness lakes: good intentions, conflicting mandates, and unintended consequences. Ecosystems, 4(4), 275-278.

Knuth, B. A., & Siemer, W. F. (2004). Fostering aquatic stewardship: a key for fisheries sustainability. In Sustainable management of North American fisheries. American Fisheries Society, Symposium (Vol. 43, pp. 243-255).

Kuehne, L. M., Olden, J. D., Strecker, A. L., Lawler, J. J., & Theobald, D. M. (2017). Past, present, and future of ecological integrity assessment for fresh waters. Frontiers in Ecology and the Environment, 15(4), 197-205.

Langhans, S. D., Domisch, S., Balbi, S., Delacámara, G., Hermoso, V., Kuemmerlene, M., … Jähniga, S.C. (2019). Combining eight research areas to foster the uptake of ecosystem-based management in fresh waters. Aquatic Conservation: Marine and Freshwater Ecosystems, 29, 1161–1173. https://doi.org/10.1002/aqc.3012

Lapointe, N.W.R., S.J. Cooke, J.G. Imhof, D. Boisclair, J.M. Casselman, R.A. Curry, O.E. Langer, R.L. McLaughlin, C.K. Minns, J.R. Post, M. Power, J.B. Rasmussen, J.D. Reynolds, J.S. Richardson, and W.M. Tonn. 2014. Principles for ensuring healthy and productive freshwater ecosystems that support sustainable fisheries. Environmental Reviews 22: 1-25.
Lawton, J. H. (1993). On the behaviour of autecologists and the crisis of extinction. Oikos, 67, 3-5.

Leopold, A. (1918). Mixing trout in western waters. Transactions of the American Fisheries Society, 47(3), 101-102.

Leopold, A. (1925). Wilderness as a form of land use. The Journal of Land & Public Utility Economics, 1(4), 398-404.

Leopold, 1934

Leopold, A. (1941). Lakes in relation to terrestrial life patterns. In Kormondy, E. J., editor. Readings in ecology, 200-203. Prentice-Hall, Englewood Cliffs, New Jersey.

Leopold, A. (1946). Erosion as a menace to the social and economic future of the Southwest. Journal of Forestry, 44(9), 627-633.

Leopold, A. (1949). A Sand County Almanac. New York: Oxford University Press.

Leopold, A. (1953). Round River. New York: Oxford University Press.

Leopold, A. (1991). Conservation Economics. In Flader, S. & Callicott, J. B., editors. The River of the Mother of God and Other Essays, 193-202. University of Wisconsin Press, Madison.

Leopold, A. C. (2004). Living with the land ethic. BioScience, 54(2), 149-154.

Leopold, Aldo. (1915). Game and Fish Handbook. Albuquerque, NM: USFS District 3.

Leopold 1999

Leopold, L. B., & Wolman, M. G. (1960). River meanders. Geological Society of America Bulletin, 71(6), 769-793.

Lindenmayer, D., & Hunter, M. (2010). Some guiding concepts for conservation biology. Conservation Biology, 24(6), 1459-1468.

Liu, J., Dietz, T., Carpenter, S. R., Alberti, M., Folke, C., Moran, E., ... & Ostrom, E. (2007a). Complexity of coupled human and natural systems. Science, 317(5844), 1513-1516.

Liu, J., Dietz, T., Carpenter, S.R., Folke, C., Alberti, M., Redman, C.L., Schneider, S.H., Ostrom, E., Pell, A.N., Lubchenco, J. and Taylor, W.W., 2007b. Coupled human and natural systems. AMBIO: a journal of the human environment, 36(8), pp.639-649.

Long, R. D., Charles, A., & Stephenson, R. L. (2015). Key principles of marine ecosystem-based management. Marine Policy, 57, 53–60. https://doi.org/10.1016/j.marpol.2015.01.013

Loury, E., S.M. Ainsley, S. Bower, R. Chuenpagdee, T. Farrell, A.G. Guthrie, S. Heng, Z. Lunn, A. Al Mamun, R. Oyanedel, S. Rocliffe, S. Satumanatpan and S.J. Cooke. (2018). Salty stories, fresh spaces: Lessons for aquatic protected areas from marine and freshwater experiences. Aquatic Conservation: Marine and Freshwater Ecosystems. 28:485–500.

Lutz Warren, J. (2010). Weaving a Wider Net for Conservation: Aldo Leopold's Water Ethic. Organization & Environment, 23(2), 220-232.

Lynch, A. J., & J. Liu. (2014). Fisheries as coupled human and natural systems. In Taylor, W. W. Lynch, A. J. & Leonard, N. J., editors. Future of Fisheries: Perspectives for Emerging Professionals, 459-466. AFS Press: Bethesda, MD.

Lynch, A. J., Beard, T. D. Jr., Cox, A., Phang, S. C., Arantes, C. C., Brummett, R. E., Cramwinckel, J. F., Gordon, L., Husen, M. A., Liu, J., Nguyen, P. H., Safari, P. K., & Zarnic, Z. (2016). Drivers and synergies in the management of inland fisheries: Searching for sustainable solutions. In Taylor, W. W., Bartley, D. M., Goddard, C. I., Leonard, N. J., & Welcomme, editors. Freshwater, fish, and the future: Proceedings of the global cross-sectoral conference, 183-200. American Fisheries Society Press: Bethesda, MD.

Monroe, J. B., Baxter, C. V., Olden, J. D., & Angermeier, P. L. (2009). Freshwaters in the public eye: understanding the role of images and media in aquatic conservation. Fisheries, 34(12), 581-585.
Newton, J. L. (2006). Aldo Leopold's odyssey: rediscovering the author of A Sand County Almanac. Island Press.

Moss, B.R., 2018. Ecology of Freshwaters: Earth's Bloodstream. John Wiley & Sons, NY.

Norton, B. G. (1988). The constancy of Leopold's land ethic. Conservation Biology, 2(1), 93-102.

Norton, B. G. (2011). What Leopold learned from Darwin and Hadley: comment on Callicott et al. Environmental Values, 20, 7-16.

Ormerod, S. J. (2014). Rebalancing the philosophy of river conservation. Aquatic Conservation: Marine and Freshwater Ecosystems, 24(2), 147-152.

Pascual, U., Balvanera, P., Díaz, S., Pataki, G., Roth, E., Stenseke, M. et al. (2017). Valuing nature's contributions to people: the IPBES approach. Current Opinion in Environmental Sustainability, 26, 7-16.

Pergams, O. R., & Zaradic, P. A. (2006). Is love of nature in the US becoming love of electronic media? 16-year downtrend in national park visits explained by watching movies, playing video games, internet use, and oil prices. Journal of environmental Management, 80(4), 387-393.

Piccolo, J. J. (2012). Stoking the "green fire": Bringing the land ethic to the water. Fisheries, 37(11), 516-518.

Piccolo, J. J. (2017). The Land Ethic and conservation of native salmonids. Ecology of Freshwater Fish, 26(1), 160-164.

Piccolo, J. J., Unfer, G., & Lobón-Cerviá, J. (2017). Why Conserve Native Brown Trout? In Lobón-Cerviá, J., & Sanz, N., editors. Brown Trout: Biology, Ecology and Management, 641-647. John Wiley & Sons Ltd.

Pilliod, D. S., & Peterson, C. R. (2001). Local and landscape effects of introduced trout on amphibians in historically fishless watersheds. Ecosystems, 4(4), 322-333.

Pister, E. P. (2001). Wilderness fish stocking: history and perspective. Ecosystems, 4(4), 279-286.

Pister, E. P. (2010). California golden trout: perspectives on restoration and management. Fisheries, 35(11), 550-553.

Pullin, A. S., Knight, T. M., Stone, D. A., & Charman, K. (2004). Do conservation managers use scientific evidence to support their decision-making?. Biological Conservation, 119(2), 245-252.

Regan, H. M., Colyvan, M., & Burgman, M. A. (2002). A taxonomy and treatment of uncertainty for ecology and conservation biology. Ecological Applications, 12(2), 618-628.

Reid, A. J., Carlson, A. K., Creed, I. F., Eliason, E. J., Gell, P. A., Johnson, P. T., et al. (2019). Emerging threats and persistent conservation challenges for freshwater biodiversity. Biological Reviews, 94(3), 849-873.

Rozzi, R. (2015). Implications of Biocultural Ethics for Earth Stewardship. Pages 113-136 In Earth Stewardship. Rozzi, R., Chapin III, F.S., Callicott, J.B., Pickett, S.T.A., Power, M.E., Armesto, J.J., & May Jr., R.H., Eds. Springer International Publishing.

Rozzi, R. (2018). Biocultural Conservation and Biocultural Ethics. Pages 303-314 In In: Ricardo Rozzi Roy H. May Jr.F. Stuart Chapin IIIFrancisca MassardoMichael C. GavinIrene J. KlaverAníbal PauchardMartin A. NuñezDaniel Simberloff (eds) From Biocultural Homogenization to Biocultural Conservation. Ecology and Ethics, vol 3. Springer, Cham. https://doi.org/10.1007/978-3-319-99513-7_19
Sacre, E., Bode, M., Weeks, R., & Pressey, R. L. (2019). The context dependence of frontier versus wilderness conservation priorities. Conservation Letters, 12(3), e12632.

Sanford, M. A., & Uglietta, J. (2010). Aldo Leopold's land ethic and the Great Lakes: A paradigm for understanding the morality of aquatic invasive species management. Student Summer Scholars Report 42, Grand Valley State University, Allendale, MI.
https://scholarworks.gvsu.edu/cgi/viewcontent.cgi?article=1041&context=sss

Saunders, D. L., Meeuwig, J. J., & Vincent, A. C. J. (2002). Freshwater protected areas: strategies for conservation. Conservation Biology, 16(1), 30-41.

Schlosser, I. J. (1991). Stream fish ecology: a landscape perspective. BioScience, 41(10), 704-712.

Schuster, R., Germain, R. R., Bennett, J. R., Reo, N. J., & Arcese, P. (2019). Vertebrate biodiversity on indigenous-managed lands in Australia, Brazil, and Canada equals that in protected areas. Environmental Science & Policy, 101, 1-6.

Scrimgeour, G.J., Hvenegaard, P.J. and Tchir, J., 2008. Cumulative industrial activity alters lotic fish assemblages in two boreal forest watersheds of Alberta, Canada. Environmental management, 42(6), pp.957-970.
Secretariat of the Convention on Biological Diversity. (2010). Strategic Plan for Biodiversity 2011-2020, including Aichi Biodiversity Targets. In Secretariat of the Convention on Biological Diversity, Nagoya, Japan.

Seitz, N.E., Westbrook, C.J. and Noble, B.F., 2011. Bringing science into river systems cumulative effects assessment practice. Environmental Impact Assessment Review, 31(3), pp.172-179.

Simberloff, D. (2012). Integrity, stability, and beauty: Aldo Leopold's evolving view of nonnative species. Environmental History, 17(3), 487-511.

Soga, M., & Gaston, K. J. (2016). Extinction of experience: the loss of human–nature interactions. Frontiers in Ecology and the Environment, 14(2), 94-101.

Strand, M., & Merritt, R.W. (1999). Impacts of livestock grazing activities on stream insect communities and the riverine environment. American Entomologist, 45, 13–29. https://doi.org/10.1093/ae/45.1.13

Suchet, S. (2002). 'Totally Wild'? Colonising discourses, indigenous knowledges and managing wildlife. Australian Geographer, 33(2), 141-157.

Sutherland, W. J., Pullin, A. S., Dolman, P. M., & Knight, T. M. (2004). The need for evidence-based conservation. Trends in ecology & evolution, 19(6), 305-308.

Swaisgood, R. R., & Sheppard, J. K. (2010). The culture of conservation biologists: show me the hope!. BioScience, 60(8), 626-630.
Tallis, H., & Lubchenco, J. (2014). Working together: A call for inclusive conservation. Nature News, 515(7525), 27.

Tickner, D., Opperman, J.J., Abell, R., Acreman, M., Arthington, A.H., Bunn, S.E., Cooke, S.J., Dalton, J., Darwall, W., Edwards, G. et al. 2020. Bending the curve of global freshwater biodiversity loss: an emergency recovery plan. BioScience, 70(4), pp.330-342.

Vaughn, G. F. (1999). The land economics of Aldo Leopold. Land Economics, 75(1), 156-159.

Vitousek, P.M., Mooney, H.A., Lubchenco, J. and Melillo, J.M., 1997. Human domination of Earth's ecosystems. Science, 277(5325), pp.494-499.
Vörösmarty, C. J., McIntyre, P. B., Gessner, M. O., Dudgeon, D., Prusevich, A., Green, P., et al. (2010). Global threats to human water security and river biodiversity. Nature, 467(7315), 555.

Walker, B. (1995). Conserving biological diversity through ecosystem resilience. Conservation Biology, 9(4), 747-752.

Walsh, C. J., Roy, A. H., Feminella, J. W., Cottingham, P. D., Groffman, P. M., & Morgan, R. P. (2005). The urban stream syndrome: current knowledge and the search for a cure. Journal of the North American Benthological Society, 24(3), 706-723.

Watson, J. E., Venter, O., Lee, J., Jones, K. R., Robinson, J. G., Possingham, H. P., & Allan, J. R. (2018). Protect the last of the wild.

Webb, J.A., Schofield, K., Peat, M., Norton, S.B., Nichols, S.J., & A. Melcher (2017). Weaving common threads in environmental causal assessment methods: toward an ideal method for rapid evidence synthesis. Freshwater Science 36(1), 250-256.

Williams, J. E., Wood, C. A., & Dombeck, M. P. (1997). Understanding watershed-scale restoration. Watershed Restoration: Principles and Practices, 1-16. AFS Press: Bethesda, MD.

Table 1. Examples of how some freshwater ecologists and practitioners were influenced by the writings of Aldo Leopold. On December 2 2018 one of the co-authors (Cooke) tweeted the following from his @SJC_fishy Twitter account: "Hey freshwater ecologists/practitioners - Did Aldo Leopold and his writings influence you in any meaningful way? I am looking for connections between Leopold and the aquatic realm." Here are some representative anonymous responses from Twitter in December of 2018.

Quotes
I'd say Leopold's succinct, eloquent presentations of basic ecological ideas went a long way to transforming me into a conservation-centred aquatic ecologist.
Leopold's essay Thinking Like a Mountain was my first introduction to trophic cascades, a concept that I (along with many other aquatic ecologists) apply every day.
Leopold's writings prompted a desire to improve my communication skills. Land and water are inextricably connected; what happens on the land impacts the aquatic environment.
The Sound County Almanac was part of what shaped my overall conservation ethic and philosophy. One of the waters I routinely survey (Les Cheneaux Islands) was where he spent some of his boyhood summers. I think of him whenever I'm working there.
While A Sand Country Almanac was foundational, his work in the Coon Valley Watershed was influential in my interests in aquatic biology, fisheries, and cooperative conservation.
I had to read "Odyssey" for my PhD exams and write about it the context of freshwater ecology. I think about it constantly since then.
Sand County Almanac and other writings by Leopold were fundamental in shaping my views of conservation and land mgmt. I was very surprised to learn recently that Sand County Almanac was not standard reading in Canadian Fish and Wildlife undergrad courses.

Figure 1. Images of Aldo Leopold showing him interacting with freshwater ecosystems in various ways. A) Leopold with a fish captured in the International Boundary Waters Canoe Area, Quetico, Canada in 1924 (http://rightsstatements.org/vocab/UND/1.0/); B) Leopold observing the Green Lagoon along the Colorado River near Baja California during field work in 1922 (http://rightsstatements.org/vocab/UND/1.0/); C) Leopold along with sons Starker and Luna canoeing at the Boundary Waters in 1925 (http://rightsstatements.org/vocab/UND/1.0/). All photos are from the Aldo Leopold Archives at the University of Wisconsin (https://uwdc.library.wisc.edu/collections/aldoleopold/).