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Perspective

Obligations of Researchers and Managers to Respect Wetlands: Practical Solutions to Minimizing Field Monitoring Impacts

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Abstract: Research and field monitoring can disturb wetland integrity. Adoption of ethical field practices is needed to limit monitoring induced stressors such as trampling, non-native seed and invertebrate dispersal, and disease and fungal spread. We identify a linear pathway of deterioration highlighting stressors that can progress to cumulative impacts, consequences, and losses at the site scale. The first step to minimize disturbance is to assess and classify the current ecosystem quality. We present a tiered framework for wetland classification and link preventative measures to the wetland tier. Preventative measures are recommended at various intensities respective to the wetland tier, with higher tiered wetlands requiring more intense preventative measures. In addition, preventative measures vary by time of implementation (before, during, and after the wetland visit) to mitigate impacts at various temporal scales. The framework is designed to increase transparency of field monitoring impacts and to promote the adoption of preventative measures. Implementing preventative measures can build accountability and foster a greater appreciation for our roles as researchers and managers in protecting wetlands.

Keywords: cleaning; efficacy; ethics; researcher impacts; wetland decontamination

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1. Call to Action for Wetland Researchers

Wetlands hold special significance to researchers and managers for a multitude of personal, professional, and public-service reasons [1]. The importance of wetlands, and their local and landscape functions, have historically been underappreciated by society [2] (pp. 15,16). Although views are shifting as researchers disseminate information on the values and ecosystem functions of wetlands such as reducing flood damage, providing clean water [3–5], preserving biodiversity, and mitigating global climate change [6–8]. These shifting attitudes in public perception are partially a result of ongoing research and education. Moreover, the importance of understanding these wetland functions in the face of climate change presents managers with an obligation to prevent further degradation, to a practical extent, during research and field monitoring events. To aid managers in encouraging researchers and monitoring personnel to maintain the ecological integrity of a wetland, we propose a conceptual framework that includes a tiered approach to classify wetland sensitivity, with guidelines for preventative measures recommended at various intensities and times of implementation to protect wetland integrity.

Activities of wetland managers and researchers should be held to a higher standard than the public's because the scientific community has an obligation to cause minimal negative impacts to the areas they conserve and study. Despite the recommended ethical field practices within the field of ecology [9–15], there is no specific guidance for wetlands.

As more research recognizes the multitude of wetland ecosystem services [16], the adoption of ethical field practices becomes a moral responsibility for researchers and managers. Alternatively, others have proposed a Universal Declaration of the Rights of Wetlands that recognizes the inherent rights of wetlands to exist unaltered from human presence [6]. Moreover, the Ramsar Convention strategic plan proposes the vision that "Wetlands are conserved, wisely used, restored and their benefits are recognized and valued by all" [17]. Our paper builds off these concepts and provides a roadmap of proactive steps that managers and researchers can follow to conserve wetland integrity. We briefly: (1) review literature on researcher- and monitoring-induced stressors and subsequent impacts and consequences to the wetland system; (2) conduct an abbreviated synthesis of successful strategies to counter these impacts; and (3) propose a tiered hierarchical approach, based on landscape function and ecological importance, to allow managers to determine practical preventative measures to better ensure protection for monitoring impacts in these wetland systems.

2. Linear Pathway of Deterioration

Researcher-induced stressors and disturbances should be understood by managers and mitigated when possible. These researcher- and monitoring-induced stressors lead to a predictable and linear pathway of deterioration, progressing from stressors to impacts to consequences to losses at the site scale. Impacts describe direct results from stressors, while consequences are the effects of these impacts. The result of these consequences leads to losses that describe partial or complete deterioration of a physical capacity or function. We describe monitoring and research-induced disturbances as four potential stressor categories: (1) physical trampling; (2) non-native seed dispersal; (3) non-native invertebrate dispersal; and (4) disease and fungal spread. These singular stressors of introduction alter structural features of wetlands and result in amplified ecosystem impacts, consequences, and losses (Figure 1).

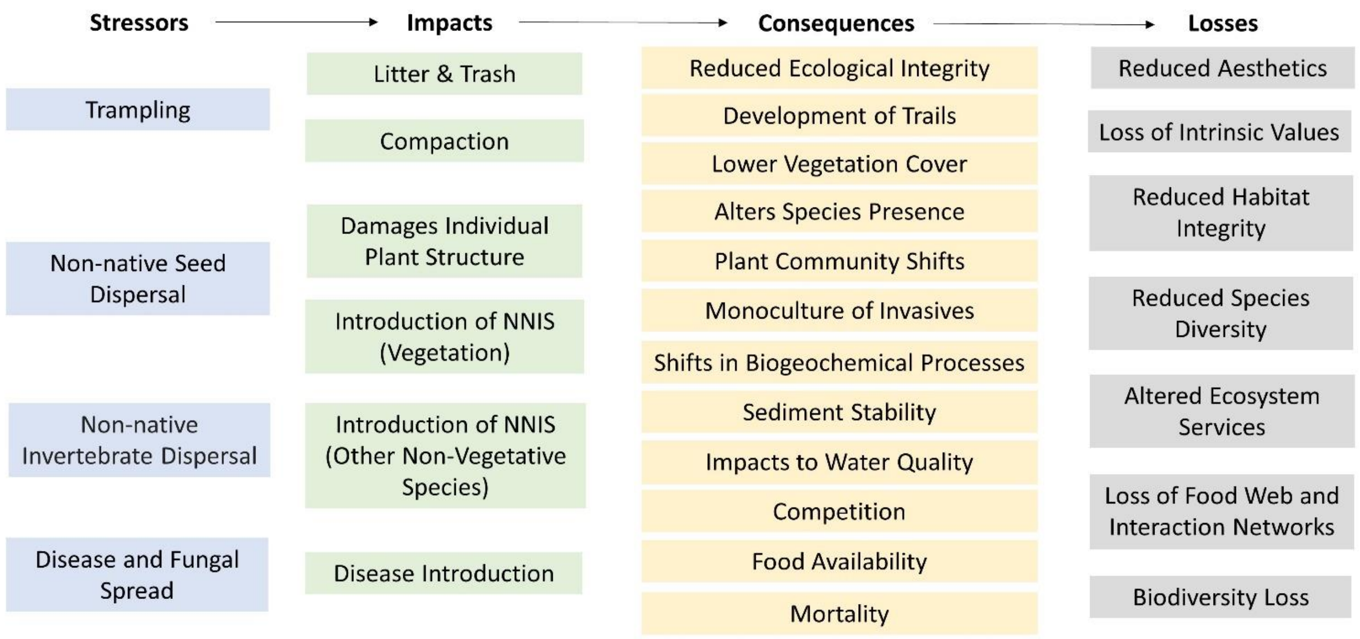

Figure 1. Researcher-induced stressors degrade ecosystem attributes down a linear pathway, progressing from impacts to consequences to ecosystem losses. NNIS = Non-native invasive species.

Physical impacts from field research are broad and can impact characteristics of wetland soil, hydrology, and vegetation [18,19]. Repeated trampling impacts vegetation height with more intensive trampling limiting vegetation cover; however ultimately declines in species richness are apparent [20]. Animal trails, which are susceptible to repetitive use like repetitive human disturbance, display higher compacted soil, more standing water, and distinctive vegetation communities different from surrounding areas [18]. While submerged community vegetation is particularly sensitive to trampling, emergent communities are particularly vulnerable to the formation of single file trails since they are much easier to walk through [21]. Generally, intensity of trampling correlates with damage to vegetation but depends on vegetation type [20,21].

To access remote study areas, often indicative of pristine or best-case conditions, the use of off-highway vehicles (i.e., airboats, motorboats, all-terrain vehicles, etc.) negatively alters and degrades the vegetation community [18,22]. Submerged and shoreline vegetation communities can become altered with repeated boat traffic, resulting wakes [23], and use of motorized vehicles resulting in the formation of deep ruts with fewer plant communities [22]. Even continued foot traffic can result in trampling of vegetation, changing the soil compaction, and subsequent hydrology to influence the vegetative structure [18]. The impacted areas typically contain fewer species, consisting of less cover [24]. Changes to wetland function fluctuates based on the intensity of the trampling [25] and individual species recovery occurs at different rates [20,26], taking as long as 15 years for recovery [20].

These small-scale disturbances can shift wetland characteristics and provide a mode for colonization of invasive species as the consistent trampling and soil compactions create pockets of disturbed microhabitats [27]. While the soil compaction is not necessarily a precursor to invasive species, it creates a transportation corridor for invasive hitchhikers carried inadvertently by researchers and others into potentially uncolonized wetlands. These invasive species may be spread via field gear and waders [28], boats [29], or even vehicles [30]. They may require specific studies and comparisons on their distribution from region to region in order to adequately assess their control [31]. The resulting invasive plants, such as reed canarygrass (*Phalaris arundinacea* L. var. *picta*) and phragmites (*Phragmites australis* Cav. Trin), can form dense monocultures [32,33] leading to a loss of native grasses [32]. These habitat changes can create disruptions to soil biota [34], wildlife communities [35–37], and insect communities on the landscape [38].

These ecosystem-disruptive invasive species are not limited to plants. New Zealand mudsnails (*Potamopyrgus antipodarum* [Gray]) outcompete native snails [39] and other macroinvertebrates within the same trophic level [40]. Other species, such as killer shrimp (*Dikerogammarus villosus* [Sowinsky]) reduce amphipod diversity of both native and other exotic species [41], and impact fish and anuran populations, preying upon larval populations [42]. The literature is replete with numerous other examples.

Researchers themselves have the potential to spread several pathogens and fungi that can have devastating effects on the surrounding ecosystems [43,44]. For example, there are two species of chytrid fungus: *Batrachochytrium dendrobatidis* (Bd), which have a global distribution, and *Batrachochytrium salamandrivorans* (Bsal), which is morphologically like Bd but currently known to only exist in Asia and Europe [45]. Both can lead to localized population crashes for amphibian communities [46–48], are believed to be spread by direct contact among frogs or through infected water [47,48], and impact over 350 amphibian host species [46]. In addition, ranaviruses are another type of disease that can spread through contact or ingestion of exposed animals [49] or exposure to infected soil and water [50]. These pathogens can lead to losses in endemic site-level biodiversity [51]. In 2015, 175 species of fish, amphibians, and reptiles were known to have been infected by viruses in the Ranavirus genus [49]. Ranavirus has led to mass die-offs in amphibians, reptiles, and fish [49,50,52], and is believed to have been spread worldwide due to the international pet trade [49,52]. The spread of Ranavirus can be deterred by disinfecting equipment and attire [53]. The spread of pathogenic bacteria and fungi is an ongoing problem within wetlands, as outbreaks of infectious diseases are occurring more frequently [51].

3. Identify Successful Intervention Strategies

Because the severity of researcher-induced impacts is dependent on timing, frequency, magnitude, and intensity, managers can suggest regulations for study design. Traversing on more durable surfaces such as rock or stone can decrease damage to vegetation [21]. In situations where this is not practical, assessing the vulnerability of vegetation to trampling based on morphological characteristics is possible [21,26] and follows a general trend of resistance with graminoids being the most resistant, and shrubs being the least resistant [20,24]. The rate of recovery for trampled vegetation increased when trampling was limited to single trails as opposed to large, trampled areas [24].

Decontamination procedures exist to limit the introduction and spread of invasive and non-native species (Table 1, Supplementary Materials Table S1). While some treatment methods may be most effective at targeting a specific invasive, bleach (Sodium hypochlorite) is often used as a universal decontaminant. Bleach has shown to be effective at eliminating aquatic invasives such as the spiny water flea (*Bythotrephes longimanus* [Leydig]) and the bloody red mysid shrimp (*Hemimysis anomala* [Sars]) [54], as well as didymo [55]. In addition, bleach is an effective treatment for both species of Chytrid fungus [56,57] and Ranavirus [53]. One notable exception is bleach does not kill New Zealand mudsnails [54].

Table 1. Methods used to control the spread of invasive plants, invertebrates, and diseases in wetlands. Concentrations, durations, target organisms, and references are found in Supplementary Materials Table S1.

Disease (Chytrid Fungus (C), Ranavirus (R), Snake Fungal Disease (S))	Aquatic Invertebrates	Invasive Vegetation (Aquatic (A), Seeds (S))
Air dry C,R	Air dry	Air dry A
Alcohol C	Alcohol	Alcohol A
Biocidal C	Bleach and water	Bleach and water A, S
Bleach and water C,R, S	Chlorine bleach	Chlorine bleach A
Chloramine-T C	Freezing	Freezing A, S
Chlorine bleach C, R	Hot water bath	Hot water bath A, S
Dettol medical C	Rinse/power wash	Rinse/power wash A
Disolol C	Steam	Steam A, S
F10 C	Virasure	
Hibiscrub C	Virkon Aquatic	
Hot water bath C, R	Virkon S®	
Kickstart C		
Nolvasan® C, R		
Potassium permanganate solution C		
QUAT-128 C		
Safe4 C		
Sodium Chloride C		
UV light R		

While bleach is effective for targeting invasives and diseases, some biota may require targeting in different ways specific to the species of invasive or disease. Other successful intervention strategies include treatments with hot water [58], air drying [29], steam treatments [59,60], and other chemicals such as Virkon Aquatic and Virasure [28,59,60]. To increase the efficacy of treatment, decontamination of clothing, boots, transportation, and all field gear is recommended [28,60].

4. Classify and Prioritize Ecosystem Sensitivity

To develop pragmatic and sensible protection measures for wetland condition monitoring or research, managers should take into consideration ecosystem sensitivity on the rate of recovery from disturbances. Our framework recognizes three categories representing a hierarchy of sensitivity characteristics that is indicative of wetland quality and significance. Our practical recommendations recognize that the most sensitive and important wetlands should have stringent safeguards to protect and maintain the exemplary functional and ecological integrity and valuable ecosystem services provided on the landscape. Whereas other wetlands fall on the spectrum of productivity and are subject to one of two lower protective tiers for minimizing the opportunity for researcher impacts. Conditions and characteristics of wetlands must be taken into consideration when identifying ecosystem sensitivity (Table 2) [61]. We note that not all conditions need to be unanimous in determining the appropriate level of protection, rather this is intended to be a guide to consider important factors in the decision. It ultimately relies on the professional judgment of the resource manager to make an informed decision that is best for protecting their wetland ecosystem.

Table 2. Classification criteria and ranking criteria for wetlands.

Ranking Criteria and Definition	A Tier	B Tier	C Tier
Rank of T&E Species: The presence and rank of threatened and endangered species, considering both global and state ranks.	Globally significant	Regional	Not present (to our knowledge)
Biodiversity: Natural assemblages of species that exist in a stable state and support ecosystem functions.	High	Moderate	Low
Ecosystem Services: Assess the functions of the wetland at their small- and large-scale roles.	Significant and unique	Moderate and multiple	Minimal or singular
Availability of Management Actions: Ownership factors influencing current and long-term management strategies such as grazing, as well as the availability of conservation resources and investments.	International, national, or regional	Regional or private	Private
Current Quality: Describes the wetland on a spectrum of natural/pristine to degraded/destroyed.	Large and/or intact	Intact or threatened	Low and/or degraded
Immediacy/Extent of Threats: Assess the scale and intensity of anthropogenic impact. Scale describes the distribution and extent of threats, and intensity describes their severity.	Minimal	Minimal and threatened	Present and extensive
Public Interest: Refers to how much the public is involved, interested, and aware of the wetland.	High	High or moderate	Low
Recovery Potential: Recognizes the disturbed and degraded state and approximates the investment of resources needed for the wetland to recover.	Low (not much to recover)	Medium (could benefit from some recovery)	High
Monitoring Difficulty: Characteristics that describe the accessibility and feasibility of access, as well as potential temporal and spatial variability difficulties.	Difficult	Difficult or moderate	Moderate or low

A Tier: Global and Regional Significance

A-Tier wetlands are globally or regionally significant and represent examples of functioning natural wetlands in an undisturbed state. These wetlands are large and/or intact wetlands with existing conservation investments under federal management, including Ramsar sites, or wetlands within a country's national park system or other protected and managed lands. A-Tier wetlands support globally endangered and threatened species, are hotspots for biodiversity, and are producers of ecosystem services based on their predominantly undisturbed state. They often provide important habitat for an imperiled species, at least temporarily (e.g., migration, stopover, breeding habitat, etc.), for some duration of the year.

B Tier: High Quality Wetlands

B-Tier wetlands comprise high quality wetlands that exist in a stable, natural state with limited signs of human impairment or are managed to support specific target organisms such as waterfowl. This tier could likely support regional and national endangered and threatened species. These may be wetlands owned by a government agency or exemplary wetlands either on private property or owned and managed by other non-government organizations and nonprofits. While these wetlands may not be among the most exemplary on the landscape, they do house locally important species, provide many ecosystem services, and are important to the overall biodiversity on the landscape. However, a notable difference from A-Tier is that they are threatened on the landscape in terms of nearby encroachment or loss.

C Tier: Low Quality Wetlands

C-Tier wetlands include low quality wetlands that are typically privately owned and have been substantially impacted by humans, which has limited or altered their functional capacity. To our knowledge, they do not currently support national or regional endangered or threatened species. Biodiversity at these wetlands is usually low and ecosystem services may be minimal or driven towards a particular function to serve human needs or infrastructure (e.g., stormwater interception and sewage overflow wetlands). These wetlands would certainly benefit from restorative actions such as wetland enhancement or restoration to provide a more diverse suite of landscape services. At the lowest end of the C-Tier spectrum, wetlands are entirely constructed or engineered and exist only to support human infrastructure (sediment ponds).

5. Recommended Preventative Measures

We propose managers instill the levels of preventative measures in research protocols reflected based on the Tiered classification. These levels of protection ascend as the recommendations provide a compelling rationale for increasing the protection to preserve the natural state (Figure 2). This phased approach to intervention requires preventative actions before, during, and after the wetland visit to mitigate impacts at various temporal scales. Pre-planning the site visit is vital to sustaining the integrity of research by proactively mitigating anticipated impacts based on the known quality of the wetland ecosystem. In addition, decontamination of clothing and field gear after the site visit is essential to limit the spread of non-native vegetation and invertebrates (Figure 3). The motivation for a tiered and ranked approach is to recognize the limitation on time and resources. This paper provides a rationale for managers to encourage the formation of specific protocols incorporating these universal, minimally intensive measures to protect the integrity of wetlands. It provides context to field staff to minimize the chance of perceived resentment as changes are implemented.

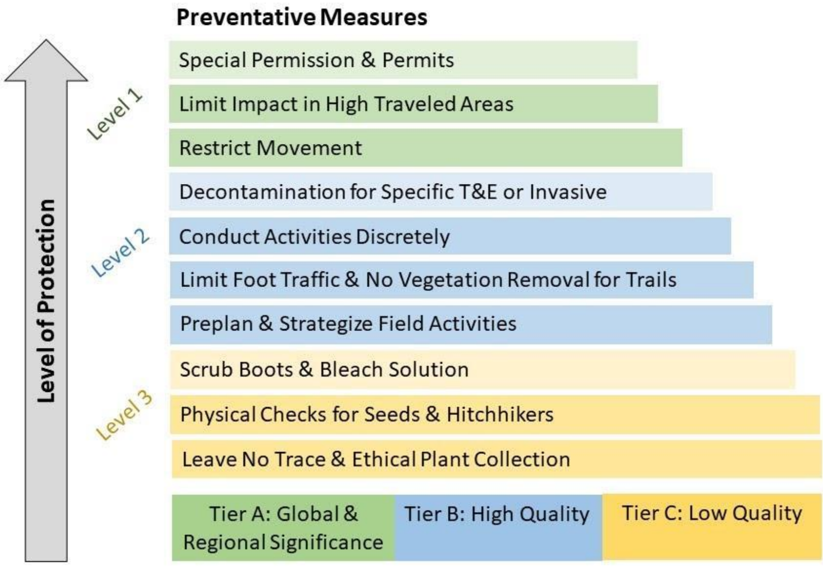

Figure 2. Recommended preventative measures for each level based on the wetland tier, where Tier A is the highest quality wetlands, Tier C is the lowest quality wetlands, and Level 1 affords the highest level of protection and includes all preventive measures included under Levels 1, 2, and 3.

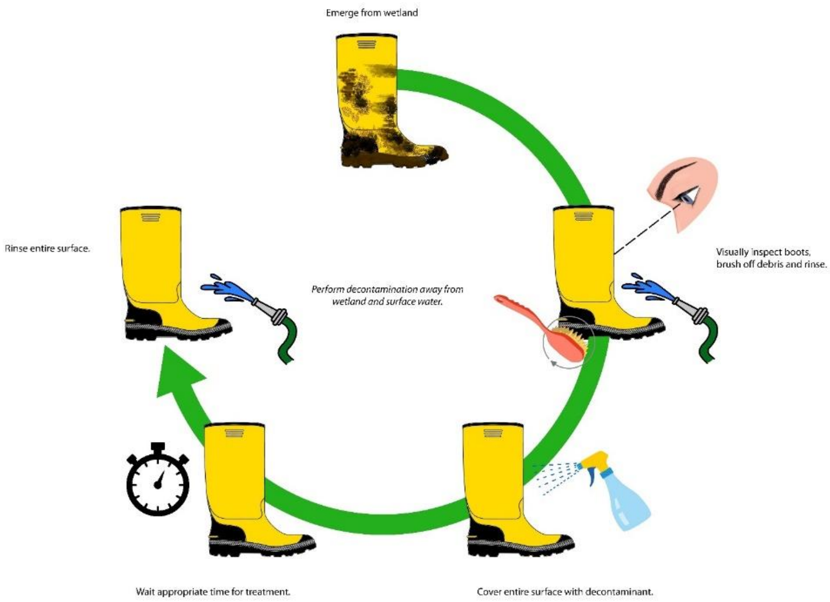

Figure 3. Decontamination steps for boots and equipment before and after entering a wetland. Treatment time varies depending on target organisms but for bleach, which is useful in most situations, a minimum of 5 min is suggested at 10% concentration (Table 1, Supplementary Materials Table S1). Decontamination procedures should occur about 200 m away from the wetland to avoid inadvertent contamination.

We believe managers understand the importance of their respective resources, and the following are intended for guidance in the development of specific protocols pertaining to research and field-monitoring staff. Generically speaking, we have divided these measures based on time of implementation including before, during, and after the site visit (Table 3).

Table 3. Managers and researchers should coordinate procedures for all activities before, during, and after site visits. These activities should reflect all preventative measures for the appropriate Tier and those below it.

Tier	Preventative Measures		
	Before Visit	**During Visit**	**After Visit**
A: Global and Regional Significance	• Plan and define steps to reduce intensity, frequency, and magnitude of study design. • Set limitations on date, duration, and purpose of visit. • Tier B preventative measures.	• Use planks or tarps in areas of high activity to minimize trampling. • Tier B preventative measures.	• List decontamination procedures at each site in a special permission permit. • Tier B preventative measures.
B: High Quality Wetlands	• Coordinate access points and travel routes to limit trampling. • Establish plan for specific threats and decontamination procedures. • Obtain scientific collection permits. • Tier C preventative measures.	• Restrict foot traffic to single trails when possible and limit use of multiple trails to decrease intensity and spatial distribution of impacts. • Avoid cutting vegetation to create trails. • Increase efforts to minimize disturbance in areas that are publicly visible. • Place soil plugs on a tarp upon excavation and return to its original layers. • Limit collecting multiple plant specimens for identification. • Tier C preventative measures.	• Organize and document plant vouchers and specimens collected. • Tier C preventative measures.
C: Low Quality Wetlands	• Identify goals and objectives. • Identify invasive and T&E species presence.	• Practice 'Leave No Trace' and conduct activities discreetly. • Minimize use of mechanized/motorized equipment unless used for specific restoration or management action. Transportation vehicle use should be prohibited in the wetland. • Back fill soil pits and do not leave open holes. • Use biodegradable materials to mark points of interest. • Follow ethical plant collection guidelines and limit intensity of harvest.	• Physically check for attached seeds or macroinvertebrates on boots, clothing, and equipment. • Scrub equipment and boots (including tread) with bristle brush. • Spray bleach solution at 5% and set for 10 minutes to eliminate wildlife diseases and invasives. • Follow decontamination guidelines for all invasives present. Bleach is not effective for certain invasive species (i.e. New Zealand mudsnail, faucet snail, Asian clam, spiny water flea eggs). • Clean and dispose of decontamination equipment and solvents away from wetland and surface waters. • Retrieve long-term monitoring equipment and markers. • Ensure efficiency and accuracy of data storage.

6. Conclusions: What's at Stake?

If managers and researchers fail to take precautions, a cascading scale of implications can occur ranging from site-specific to broader-scale inclusions. Researcher-induced stressors lead to a linear pathway of degradation, progressing from stressors to impacts to consequences and losses at the site scale. Impacts can potentially skew data collection and lead to biased results and misrepresentation of ecosystem attributes. In addition, research is often conducted in remote areas where the researcher is not part of the local community. Managers and researchers have a duty to collect accurate and representative ecological attributes, but also to act as ambassadors to the local populations, peers, and the next generation of researchers and field staff in demonstrating the importance and value of the site, and by extension, research through their actions. A failure to convey this reverence and importance to the resource does the field of science a disservice and may contribute to a cultural loss of trust in the scientific process and those that conduct research (Figure 4).

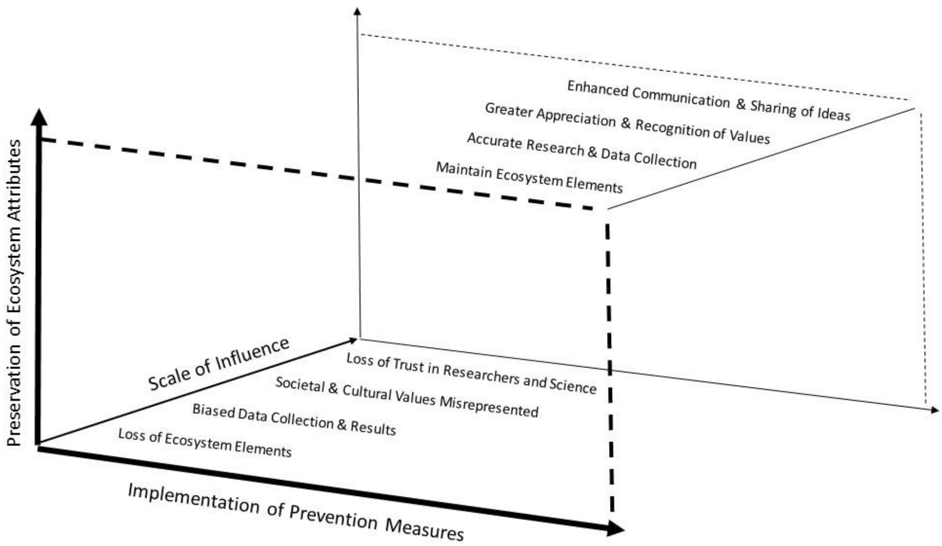

Figure 4. Consequences from research-induced impacts result in a cascading scale, ranging from local disturbances to broader societal consequences. When no preventative measures are taken, researchers' fail to fulfill their duty at the site level, and this can lead to a loss of trust in science at the societal scale. Embracing preventative measures allows ecosystem attributes to persist and leads to greater appreciation of wetlands and enhanced communication between stakeholders.

Science is grounded in observations and gains strength through collaboration and sharing of ideas. At the foundational level, researchers must accept the inherent rights of wetland ecosystems to exist unaltered from human presence [6], especially researcher-induced impacts. Wetlands exist singularly within the natural world, and the researcher is a visitor who does not remain. Our role should be to design unbiased studies that capture the best representation of ecosystem processes. It is incredibly important to control what we can and limit direct stresses to the wetland ecosystem. Researchers should feel empowered to reduce impacts and limit disturbance to preserve ecosystem integrity, increase credence in the scientific community, and foster a greater appreciation for the intrinsic value of wetlands. When preventative measures are implemented, ecosystem attributes are retained, creating a better perspective and representation of wetlands, while also protecting their integrity and the integrity of the researcher.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/land11040481/s1, References [62–64] are cited in the supplementary materials, Table S1: Table of cleaning and decontamination protocols.

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