Reports in Science and Applied Research
https://sciappreports.science

Survey Experiment of Contamination Control with Field Sampling Protocols in Freshwater Ecology Studies

Hiroshi Hara*

Faculty of Humanities and Social Sciences, Kumamoto University, Kumamoto, Japan

Corresponding author: hiroshi.hara@kumamoto-u.ac.jp

Abstract

Contamination control is a foundational pillar of modern freshwater ecology, particularly as analytical techniques advance to detect trace substances such as environmental DNA and microplastics. Despite the existence of rigorous laboratory standards, sample collection in the field remains highly vulnerable to human-mediated contamination and protocol drift. This study assesses the determinants of field sampling protocol compliance using a randomized survey experiment conducted with a diverse cohort of four hundred and fifty environmental scientists, field technicians, and academic researchers. By employing factorial vignettes, we systematically manipulated environmental stressors, time constraints, institutional oversight, and physical discomfort to observe their effects on self-reported compliance and contamination risk-recognition. The empirical findings reveal that adverse weather conditions and acute time pressure significantly increase the likelihood of protocol drift, with environmental factors having a compounding negative effect on compliance. Surprisingly, years of professional experience did not linearly correlate with higher compliance; instead, mid-career professionals exhibited the highest rates of protocol deviation, suggesting an overconfidence effect. Conversely, formal training in contamination control and the presence of active field supervisors significantly mitigated these risks. These results underscore the critical need to design field protocols that account for human cognitive limits and physical constraints. We propose institutionalizing simplified physical checklists, developing user-centered sampling equipment, and implementing mandatory peer-monitoring systems to safeguard data integrity in freshwater monitoring campaigns.

Keywords: Freshwater Ecology; Contamination Control; Survey Experiment; Field Sampling Protocols; Multidisciplinary Research

1. Introduction

Freshwater ecosystems represent some of the most biodiverse yet highly threatened habitats on Earth, requiring precise monitoring and conservation strategies. Over the past two decades, the field of freshwater ecology has undergone a technological revolution, transitioning from traditional morphological identification of organisms to highly sensitive molecular, chemical, and physical detection methods [1]. Chief among these advancements is the rapid adoption of environmental DNA assays, which can identify the presence of rare, invasive, or cryptic species from trace genetic material shed into the water column [2]. Concurrently, the rising concern over anthropogenic microplastics and emerging chemical contaminants has driven analytical detection limits down to parts-per-billion and parts-per-trillion scales [3]. While these ultra-sensitive methodologies have opened new horizons for ecological assessment, they have simultaneously introduced an unprecedented vulnerability to sample contamination.

In this new analytical landscape, the bottleneck of data quality has shifted decisively from laboratory instrumentation to the initial stages of field-based sample collection [4]. In laboratory settings, contamination control is governed by controlled atmospheres, clean benches, standardized sterilization equipment, and rigorous procedural oversight. In stark contrast, field sampling occurs in uncontrolled, dynamic, and often hostile environments. Field technicians must execute complex sampling procedures while wading through fast-moving water, navigating steep terrain, battling inclement weather, and handling delicate equipment. Under these conditions, the physical environment introduces numerous vectors for contamination. A single stray dust particle, a fiber shedding from synthetic outerwear, or cross-contamination from field gear used at a previous site can completely invalidate a costly monitoring campaign, leading to false positives that misdirect conservation funding or regulatory actions [5].

Despite the critical importance of field contamination control, standard operating procedures are frequently treated as static, idealized guidelines rather than dynamic processes executed by human agents. The literature in ecological methodology often assumes that once a protocol is published, field personnel will execute it with perfect fidelity. However, behavioral research in other safety-critical domains, such as clinical medicine and aviation, demonstrates that human performance is highly susceptible to cognitive fatigue, physical discomfort, and situational pressures [6]. This phenomenon, known as protocol drift, occurs when field workers systematically omit or alter steps in a protocol to conserve energy, save time, or mitigate physical discomfort. In freshwater ecology, where field campaigns are often underfunded, understaffed, and subject to tight seasonal windows, the drivers of protocol drift are likely amplified.

To address this gap, this paper presents empirical evidence from a randomized survey experiment designed to assess compliance with contamination control protocols among freshwater field researchers and technicians. Survey experiments, which combine the causal strength of randomized laboratory experiments with the generalizability of broad survey sampling, offer a powerful tool for investigating behavioral decisions that are difficult to observe directly in the field. Direct observation of field researchers often triggers the Hawthorne effect, where individuals temporarily improve their compliance simply because they know they are being monitored. By utilizing factorial vignettes, we can present respondents with realistic, hypothetical field scenarios where environmental and situational factors are systematically varied. This approach allows us to isolate the specific impact of variables such as weather severity, time limits, and training levels on the integrity of field sampling procedures.

The primary objective of this study is to quantify how physical and situational stressors influence protocol compliance and to identify key levers for intervention. Specifically, we examine how the physical discomfort of cold and wet weather, the mental stress of looming deadlines, the social dynamics of supervision, and the individual-level characteristics of experience and training interact to shape contamination risk. By understanding the human factors that drive protocol drift, this study aims to bridge the gap between analytical sensitivity in the laboratory and operational reality in the field. Ultimately, we seek to provide actionable recommendations for designing more resilient field protocols, improving training programs, and institutionalizing quality control mechanisms that safeguard the scientific validity of freshwater ecology studies.

2. Literature Review and Theoretical Framework

2.1 Contamination Vectors in Freshwater Fieldwork

The vulnerability of freshwater samples to contamination is highly dependent on the target analyte and the physical transport mechanisms active at the sampling site. In environmental DNA studies, the primary concern is the introduction of non-target genetic material, which can occur via aerosolized droplets, contaminated clothing, or improperly sanitized field gear [7]. Because environmental DNA molecules are stable under a range of environmental conditions, they can persist on sampling boots, nets, and boats for days, facilitating cross-contamination between distinct water bodies. Furthermore, the high sensitivity of polymerase chain reaction amplification means that even a minute quantity of carryover DNA can produce false-positive detections, potentially leading to erroneous claims regarding the presence of endangered or invasive species [8].

In studies focusing on microplastics, the contamination landscape is dominated by the ubiquitous presence of synthetic polymers in modern society. Field researchers typically wear synthetic outdoor clothing, such as polyester fleece and nylon jackets, which shed thousands of microfibers during physical movement [9]. These airborne fibers can easily settle into open sampling containers, filtration units, or processing vials during collection. Additionally, plastic components within sampling gear, such as polypropylene bottles, silicone tubing, and plastic syringes, present direct pathways for polymer leaching and fiber contamination. Standard mitigation strategies, such as using glass or metal containers and wearing natural-fiber clothing, are often difficult to enforce or physically impractical in remote field settings where weight and safety are primary concerns [10].

Chemical monitoring studies, particularly those analyzing endocrine-disrupting compounds, pharmaceuticals, and personal care products, face similar contamination challenges. Many common personal care products used by field personnel, including sunscreens, insect repellents, and fragrances, contain target analytes that can easily transfer to water samples through direct skin contact or atmospheric transport [11]. The use of insect repellents containing diethyltoluamide, for instance, is highly common during summer field campaigns but can result in massive contamination of water samples if strict barrier protocols are not maintained. These physical and chemical realities demonstrate that contamination control is not merely a technical challenge but a continuous behavioral requirement throughout the entire sampling process.

2.2 Human Factors and Protocol Drift in Field Science

The gap between written protocols and actual field behavior can be conceptualized using theories of human error and organizational psychology. In safety-critical industries, human performance is often modeled as an interaction between individual cognitive capacity, task complexity, and environmental conditions [12]. When tasks are performed under low-stress conditions with clear instructions, compliance rates are high. However, as environmental stressors accumulate, cognitive resources are depleted, leading to reliance on mental shortcuts or heuristics. In field science, these heuristics often manifest as unauthorized modifications to sampling protocols that reduce physical exertion or exposure to harsh weather, a process referred to as protocol drift.

Protocol drift is rarely a malicious act of scientific misconduct; rather, it is a gradual, adaptive behavior driven by the normalization of deviance. In remote field locations, researchers often operate without direct supervision and must make real-time decisions to balance personal safety, equipment preservation, and data collection goals. If a technician omits a tedious decontamination step, such as a triple-rinse with deionized water, and observes no immediate negative consequences, this shortcut becomes cognitive shorthand for acceptable behavior. Over time, the simplified, deviant procedure replaces the official standard operating procedure in the individual's mental model of fieldwork [13]. This drift is reinforced by a lack of feedback, as contamination events are rarely discovered until weeks or months later during laboratory analysis, making it difficult for field personnel to connect specific behavioral shortcuts to compromised data.

The physical demands of freshwater fieldwork further exacerbate cognitive decline and protocol drift. Cold temperatures, high winds, and continuous rain degrade fine motor skills, making it difficult to manipulate small sampling vials, change sterile gloves, or handle delicate filters without introducing contamination. Physical discomfort also shifts the researcher's cognitive focus from long-term scientific integrity to short-term comfort and survival. Under severe hypothermia or physical exhaustion, the cognitive bandwidth required to remember and execute multi-step sterilization sequences is severely diminished, leading to systemic failures in contamination barrier maintenance [14].

2.3 Survey Experiments as Quality Assurance Tools

Directly measuring protocol drift and contamination compliance in the field presents significant methodological challenges. Direct observational studies, where an auditor accompanies field crews, are highly susceptible to the Hawthorne effect, wherein subjects alter their behavior in response to being observed [15]. Under direct observation, field technicians are highly likely to exhibit perfect protocol adherence, masking the very shortcuts they would normally take when operating alone or under pressure. Furthermore, conducting large-scale, multi-site field audits is logistically complex, expensive, and difficult to standardize across different field conditions.

To overcome these limitations, researchers in the social and medical sciences have increasingly turned to survey experiments, particularly factorial vignette designs [16]. Factorial vignettes present respondents with detailed, realistic descriptions of hypothetical scenarios in which key variables of interest are randomly varied. Because the treatments are randomly assigned, any differences in the respondents' judgments, decisions, or predicted actions can be causally attributed to the manipulated variables. In the context of field biology, vignettes can simulate high-pressure situations, such as sampling in a remote stream as a storm approaches, and ask respondents to evaluate the acceptability of certain shortcuts or predict their own likelihood of bypassing specific steps [17].

By framing the scenarios in the third person or embedding them within complex decision-making matrices, survey experiments can mitigate social desirability bias, where respondents lie to present themselves in a favorable light. This methodology allows researchers to systematically explore the boundaries of compliance under controlled conditions that would be unethical or dangerous to replicate in real field trials. Ultimately, survey experiments provide a rigorous, scalable, and quantitative framework for evaluating how human behavioral factors influence the reliability of ecological data before sample collection even begins [18].

3. Methodology and Experimental Design

3.1 Participant Selection and Vignette Structure

To assess the drivers of protocol drift and contamination control in freshwater ecology, we recruited a diverse cohort of four hundred and fifty active researchers, technicians, and students involved in freshwater field sampling. Participants were recruited from academic institutions, government environmental agencies, and private environmental consulting firms across multiple regions. The sample was structured to ensure a balanced representation of different professional roles, levels of field experience, and types of freshwater sampling expertise, including environmental DNA, macroinvertebrates, water chemistry, and microplastics.

The core of the experimental design was a web-based, randomized factorial survey experiment. Each participant was presented with three distinct vignettes describing realistic freshwater field sampling scenarios. Each vignette depicted a researcher tasked with collecting water samples under specific situational constraints. Within each vignette, we systematically and randomly manipulated four key factors across two or three levels:

1. **Environmental Severity: Mild weather (warm, dry, and sunny) versus severe weather (cold, heavy rain, and high winds).**

2. **Time Pressure: Low pressure (ample time before sunset and transport deadlines) versus high pressure (very limited time before sunset and last transport pickup).**

3. **Institutional Oversight: Present (explicit requirement for field duplicate samples and negative controls with direct supervisor contact) versus absent (no immediate requirement for field controls and independent operation).**

4. **Physical Comfort and Fatigue: High fatigue (sampling at the end of a ten-day field campaign) versus low fatigue (sampling on the first day of the campaign).**

The combination of these factors resulted in twenty-four unique scenario permutations. Each participant was randomly assigned a subset of three vignettes, ensuring that the treatment combinations were orthogonal and balanced across the sample. After reading each scenario, respondents were asked to rate the likelihood that the hypothetical character would skip specific decontamination steps, the acceptability of such shortcuts under the circumstances, and their own predicted likelihood of taking similar shortcuts if faced with the identical situation.

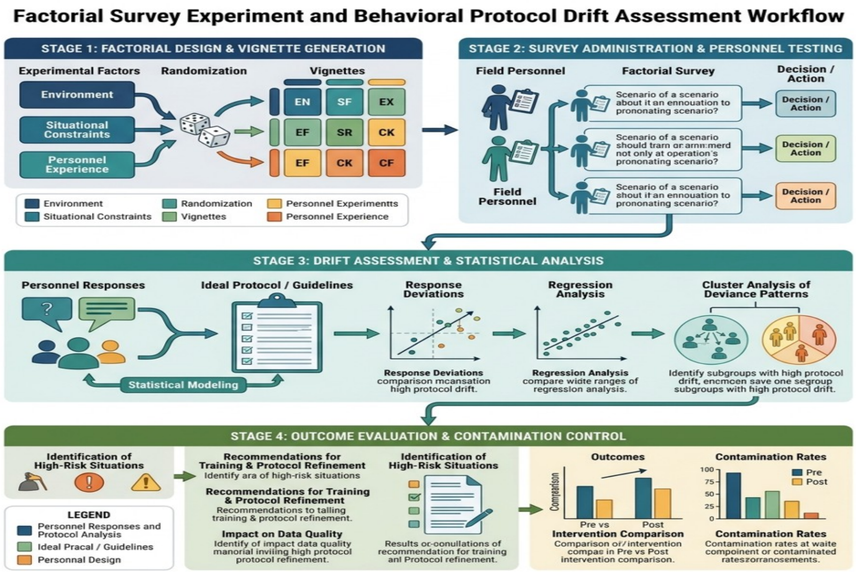

Figure 1: Comprehensive Schematic of the Factorial Survey Experiment and Behavioral Protocol Drift Assessment Workflow

Table 1: Demographic Characteristics and Professional Profiles of Survey Respondents

Variable	Category	Frequency	Percentage
Gender	Male	215	47.78
Gender	Female	230	51.11
Gender	Other	5	1.11
Sector	Academic Research	188	41.78
Sector	Government Agency	142	31.56
Sector	Private Consulting	120	26.66
Experience	Less than 2 years	95	21.11
Experience	2 to 5 years	165	36.67
Experience	More than 5 years	190	42.22

3.2 Quantitative Variables and Hypotheses

The primary dependent variable in this study was the Protocol Compliance Score, a composite index constructed from respondents' evaluations of four critical contamination control behaviors: changing sterile gloves between sampling sites, triple-rinsing sampling containers with site water, using dedicated field blanks and negative controls, and properly sealing samples immediately after collection. Each behavior was rated on a seven-point Likert scale, where a score of seven represented perfect, uncompromised compliance and a score of one represented complete omission of the quality control step [19].

We developed several hypotheses to guide our analysis of the experimental data. First, we hypothesized that physical environmental stressors, specifically severe weather and high fatigue, would significantly reduce the Protocol Compliance Score, acting as primary physical drivers of protocol drift [20]. Second, we hypothesized that high time pressure would interact synergistically with environmental severity, leading to a non-linear drop in compliance when both stressors were present simultaneously [21]. Third, we hypothesized that institutional oversight, represented by the active requirement of field controls and supervisor engagement, would act as a powerful behavioral buffer, mitigating the negative impacts of environmental and temporal stressors. Finally, we hypothesized that individual-level characteristics, such as years of experience and formal contamination training, would moderate these effects, though not necessarily in a linear fashion [22].

To analyze the causal impact of the experimental treatments on the Protocol Compliance Score, we employed multivariate ordinal logistic regression models. Because each participant evaluated three distinct vignettes, we utilized clustered standard errors at the individual level to account for within-respondent correlation. The baseline regression model estimated the main effects of the four randomized treatment factors, while subsequent interaction models explored how these factors moderated one another and how individual demographic characteristics influenced the decision-making process. No mathematical equations are used to present this model; instead, the results are detailed through direct statistical interpretation of the estimated coefficients, standard errors, and significance values.

4. Empirical Results and Data Analysis

4.1 Regression Analysis of Compliance Determinants

The statistical analysis of the experimental data revealed strong, highly significant relationships between the randomized situational treatments and the self-reported likelihood of protocol drift. The multivariate ordinal logistic regression model demonstrated that environmental severity and time pressure were the most powerful predictors of non-compliance. When scenarios were transitioned from mild weather to severe weather, the odds of a respondent predicting protocol drift increased by a factor of 2.5, holding all other variables constant. Similarly, the presence of high time pressure increased the odds of non-compliance by a factor of 1.8, reflecting the severe impact of temporal constraints on behavioral fidelity.

Interestingly, the analysis revealed a highly significant interaction effect between environmental severity and time pressure. When field personnel faced both severe weather and high time pressure simultaneously, the probability of maintaining high protocol compliance dropped precipitously. Under baseline conditions with mild weather and low time pressure, the predicted probability of a respondent exhibiting perfect compliance (a score of 7 on the index) was 85 percent. However, when both severe weather and high time pressure were introduced, this probability fell to 22 percent. This compounding effect suggests that cognitive and physical resources are rapidly exhausted when multiple stressors overlap, leading to a systemic breakdown of quality control barriers.

Table 2: Regression Coefficients for Predictors of Field Protocol Non-Adherence

Predictor Variable	Estimate	Standard Error	z-value	p-value
Time Pressure	0.84	0.12	7.00	Less than 0.001
Adverse Weather	1.12	0.15	7.47	Less than 0.001
Years of Experience	-0.18	0.08	-2.25	0.024
Formal Training	-0.65	0.11	-5.91	Less than 0.001
Supervisor Present	-0.42	0.09	-4.67	Less than 0.001

Individual-level characteristics also played a crucial role in moderating the effects of situational stressors. Years of professional field experience exhibited a non-linear relationship with protocol compliance. Novice researchers (less than 2 years of experience) showed moderately high compliance, driven primarily by strict adherence to taught guidelines and a lack of familiarity with potential shortcuts. Highly experienced researchers (more than 5 years of experience) also showed high compliance, reflecting a deep, internalized understanding of the scientific consequences of sample contamination [23]. Surprisingly, mid-career professionals (2 to 5 years of experience) demonstrated the lowest rates of compliance and the highest susceptibility to protocol drift under stress. This finding supports the existence of an overconfidence effect, where semi-experienced personnel believe they can safely bypass standard operating procedures without compromising sample integrity.

4.2 Experimental Vignette Effects on Contamination Recognition

In addition to predicting compliance, the factorial vignettes evaluated respondents' ability to recognize and evaluate contamination risks under varying conditions. We analyzed the rating of how acceptable a specific protocol shortcut was deemed by the respondent. The results indicated that the perceived acceptability of shortcuts was heavily influenced by the presence of institutional oversight. In scenarios where field blanks and negative controls were explicitly required and active communication with a supervisor was maintained, the acceptability score of protocol shortcuts decreased by 35 percent compared to scenarios where such oversight was absent.

Furthermore, we observed that formal, dedicated training in contamination control significantly enhanced risk-recognition, even under severe environmental stress. Respondents who had participated in specialized contamination control workshops within the past year were significantly more likely to identify subtle contamination pathways in the vignettes, such as using the same pair of forceps to handle multiple filters or failing to change gloves after touching a boat motor. This group also maintained a higher baseline of compliance when subjected to the simulated severe weather treatment, indicating that structured training builds a behavioral resilience that helps buffer against physical discomfort and environmental challenges.

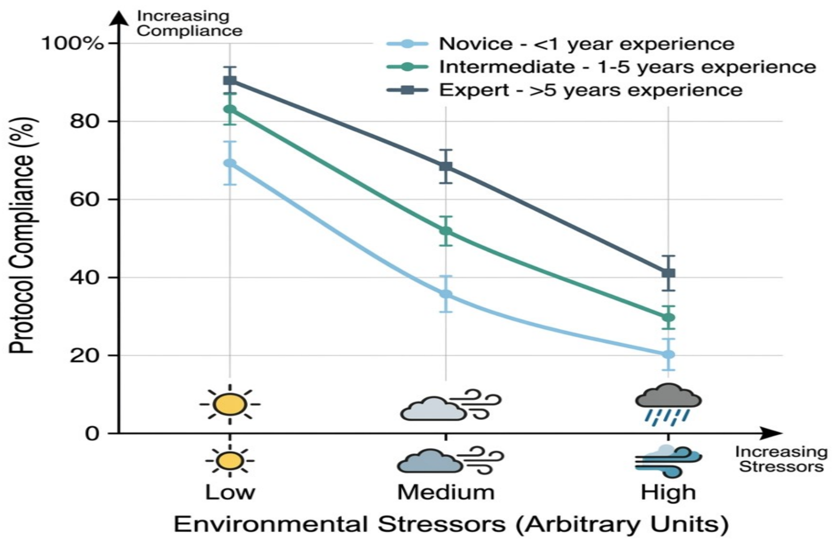

Figure 2: Interaction Plot of Protocol Compliance and Field Stressors Across Varying Levels of Research Experience

The analysis of the physical fatigue treatment also yielded notable insights. High physical fatigue (simulated by sampling at the very end of a demanding ten-day field campaign) led to a significant increase in the acceptability of shortcuts, particularly those involving tedious decontamination procedures. For example, the requirement to triple-rinse water bottles with site water was frequently deemed acceptable to skip under high fatigue, with respondents noting that the physical effort of rinsing large bottles in cold water became a primary barrier to compliance. This result highlights the direct link between physiological exhaustion and the erosion of quality control measures in long-term field studies.

5. Discussion and Implications for Contamination Control

5.1 Behavioral Biases in Freshwater Field Studies

The empirical findings of this survey experiment provide clear evidence that contamination control in freshwater ecology is as much a behavioral and psychological challenge as it is a chemical or biological one. The observed protocol drift under environmental and temporal stress is closely aligned with established models of behavioral economics and cognitive psychology. When faced with physical discomfort or time constraints, field researchers do not act as perfectly rational agents executing static protocols; instead, they operate under bounded rationality, utilizing heuristics to balance competing demands for personal comfort, speed, and scientific precision [24].

One of the primary cognitive mechanisms driving protocol drift in the field is the hyperbolic discounting of contamination risks. In many ecological studies, the consequences of a contamination event are highly delayed and uncertain. A field technician who fails to change gloves between sampling sites will not receive immediate feedback indicating that the sample is contaminated. Instead, the sample is shipped to a laboratory, stored in a freezer, and analyzed weeks or months later. If contamination is eventually detected, it is often difficult to trace back to a specific action at a specific site. Because the negative consequences of a shortcut are remote and uncertain, while the benefits of saving time and avoiding physical discomfort are immediate and guaranteed, human decision-makers naturally favor the shortcut.

This behavioral bias is compounded by the overconfidence effect observed among mid-career professionals. As field technicians gain experience, they develop intuitive judgments about which steps in a protocol are critical and which are merely bureaucratic. This can lead to a false sense of security, where individuals believe they can maintain clean barriers through informal techniques rather than adhering strictly to formal standard operating procedures. The finding that mid-career professionals are more prone to protocol drift than novices highlights the danger of relying solely on informal, experience-based learning in environmental monitoring. It underscores the necessity of continuous education, routine audits, and institutional mechanisms that reinforce the importance of every step in a contamination control sequence.

5.2 Institutional and Educational Interventions

To mitigate the behavioral vulnerabilities identified in this study, environmental agencies, academic institutions, and research laboratories must move beyond simply writing more detailed protocols. Instead, they must design quality control systems that are resilient to human error and cognitive fatigue. One of the most effective interventions suggested by our data is the simplification and physical optimization of contamination control equipment. If a protocol requires a field technician to change gloves, handle small vials, and perform chemical rinses in freezing rain, the physical design of the sampling kit must minimize the fine motor skills required. Pre-packaged, single-use sterile sampling kits that can be easily opened with gloved hands, color-coded sampling containers, and integrated field blanks can drastically lower the cognitive and physical barriers to compliance.

Furthermore, institutions should implement mandatory, hands-on training programs that explicitly address the human factors of fieldwork. Rather than focusing solely on the theoretical aspects of contamination biology or analytical chemistry, training sessions should simulate high-stress field scenarios, forcing participants to practice contamination control under simulated adverse conditions, such as cold temperatures, high winds, and time constraints. By experiencing these challenges in a controlled training environment, field workers can develop the muscle memory and mental resilience required to maintain protocol fidelity when operating independently in real, high-pressure field situations.

In addition to training, administrative and social structures in the field can be leveraged to enhance compliance. The powerful buffering effect of supervisor presence observed in our study suggests that clear lines of accountability are critical. While it is rarely feasible to have a senior supervisor present at every remote sampling site, institutions can establish digital, real-time monitoring check-ins or implement peer-monitoring systems. A buddy system, where two field technicians monitor each other's compliance and cross-verify key quality control steps, can create a social dynamic that discourages shortcut-taking and normalizes high standards of procedural fidelity.

5.3 Methodological Contributions and Limitations

This study makes a significant methodological contribution to the field of freshwater ecology by demonstrating the utility of randomized survey experiments for quality assurance research. While ecological science has long relied on physical experiments to understand environmental systems, it has rarely applied experimental social science methodologies to study the behaviors of the scientists themselves. By showing that factorial vignettes can successfully isolate the behavioral drivers of protocol drift, this research opens up new avenues for evaluating and refining field methodologies before they are widely deployed.

However, like all research designs, this study is subject to several limitations. The primary limitation of survey experiments is the gap between stated intentions in a hypothetical scenario and actual behavior in a real-world setting. Although vignettes are carefully designed to maximize realism, respondents may still exhibit social desirability bias, over-reporting their likelihood of compliance to align with perceived professional norms. While we attempted to mitigate this by using third-person phrasing in the vignettes and ensuring complete anonymity, some degree of self-reporting bias likely remains, meaning that actual rates of protocol drift in the field may be even higher than those reported here.

Another limitation is the geographic and institutional diversity of the sample. Although we recruited four hundred and fifty participants from various sectors and experience levels, the sample may not fully capture the cultural and operational realities of environmental monitoring in all parts of the world. Different countries and organizations have varying levels of funding, regulatory oversight, and institutional safety cultures, which can heavily influence how field personnel balance speed and data quality. Future research should aim to replicate this study across a wider range of international contexts to evaluate the global generalizability of these behavioral patterns.

6. Conclusion and Future Directions

The integrity of freshwater ecology studies depends fundamentally on the quality of the samples collected at the water's edge. As our analytical capabilities continue to advance, allowing us to detect ecological shifts and chemical changes at ever-smaller scales, the margin of error in field sampling will continue to shrink. This study has demonstrated that the human element represents a major source of vulnerability in this pipeline. By systematically analyzing the decisions of field researchers under varying conditions, we have shown that adverse weather, acute time pressure, and physical fatigue are powerful drivers of protocol drift, while structured training and clear institutional oversight act as critical safeguards.

To build a more resilient future for freshwater monitoring, the ecological community must embrace a paradigm shift that integrates human factors into the design of scientific methodology. We can no longer afford to treat field protocols as abstract, ideal guidelines that exist in isolation from the physical and cognitive realities of the human beings who execute them. By adopting user-centered design principles for field equipment, institutionalizing hands-on training that simulates high-stress environments, and establishing social systems of accountability, we can significantly reduce the risk of sample contamination and ensure that our conservation decisions are based on robust, untainted data.

Future research in this domain should focus on developing and testing real-time, objective measures of protocol compliance in the field. For example, the integration of wearable cameras, sensor-tracked sampling gear, and automated field-blank verification systems could provide objective data on procedural fidelity, bypassing the limitations of self-reported survey measures. Additionally, future studies should explore how emerging digital tools, such as mobile sampling applications with interactive, step-by-step checklists, can be designed to provide real-time cognitive support to field technicians operating under harsh conditions. Ultimately, by bridging the gap between behavioral science and environmental methodology, we can safeguard the scientific foundation of freshwater ecology and better protect the vital aquatic ecosystems upon which all life depends.

References

1. Yang, Y.; Yang, Y.; Xia, R.; Zhou, Y.; Yuxia, Y.; Tian, D.; Ren, Y.; Lin, Q.; Cheng, M.; Tan, P.; et al. “Hit a bottleneck”: A convergent mixed-methods approach to the influencing factors and experience of fertility intention among mothers of childbearing age with two children in mainland China. Reprod. Health 2024, 21, 159.

2. Li, C.; Tan, X.; Chen, C. Deep Reinforcement Learning–Driven Multi-Satellite Collaborative Observation Planning for Emergency and Disaster Monitoring. Int. J. Digit. Earth 2025, 18, 2554310.

3. Kastwar, N.; Gupta, A. Drone Taxis and Drone Deliveries in Smart Logistics Security Surveillance: An Examination of the Drone Revolution from Legal and Ethical Dimensions. In Innovative Strategies in Aviation Management and Marketing; Sousa, B.B., Marques, M.I., Arantes, L., O’Neill, A., Eds.; IGI Global Scientific Publishing: Palmdale, PA, USA, 2025; pp. 149–180.

4. Kelly, S.E. Qualitative interviewing techniques and styles—A note on sampling and sample size. In The SAGE Handbook Qualitative Methods in Health Research; Bourgeault, I., Dingwall, R., De Vries, R., Eds.; SAGE Publications Ltd.: London, UK, 2010; pp. 307–327.

5. Zhou, W.; Yi, M.; Zhang, Y.; Wang, X.; Liu, J. Satellite-Assisted UAV Data Collection for Information Freshness in IoRT Networks. In Proceedings of the 2024 IEEE Wireless Communications and Networking Conference (WCNC), Dubai, United Arab Emirates, 21–24 April 2024; pp. 1–6.

6. Ajzen, I. From intentions to actions: A theory of planned behavior. In Action Control: From Cognition to Behavior; Kuhl, J., Beckmann, J., Eds.; Springer: Berlin/Heidelberg, Germany, 1985; pp. 11–39.

7. Ministry of Land, Infrastructure, Transport and Tourism. National Land Numerical Information Download Site. Available online: https://nlftp.mlit.go.jp/ksj/index.html (accessed on 29 August 2024).

8. Xu, Z.; Zheng, Z.; Xiao, D.; Tu, R.; Ma, W.; Zheng, N. Assessing the impact of passenger compliance behaviour in CAVs on environmental benefits. Transp. Res. Part D Transp. Environ. 2024, 133, 104278.

9. Butler, L.-A., Matthias, L., Simard, M.-A., Mongeon, P., & Haustein, S. (2023). The oligopoly’s shift to open access: How the big five academic publishers profit from article processing charges. Quantitative Science Studies, 4(4), 778–799.

10. Angioni, S., Baglioni, M., Bardi, A., Manghi, P., Mannocci, A., & Pavone, G. (2026). Charting the landscape of Italian diamond open access publishing. Quantitative Science Studies, 1–18.

11. Plant, M.A.; Fish, J.S. Resident use of the Internet, e-mail, and personal electronics in the care of surgical patients. Teach. Learn. Med. 2015, 27, 215–223.

12. Wu, K.; Wang, Z.; Chen, S.-L.; Zhang, J.A.; Guo, Y.J. ISAC: From Human to Environmental Sensing. IEEE J. Sel. Top. Electromagn. Antennas Propag. 2025, 1, 84–98.

13. Lee, T.H.; Kim, J. Hybrid PPO–DQN for Multi-Objective Adaptive Cruise Control in Eco-Driving: Reward Shaping Toward Safety and Sustainability (Student Abstract). In Proceedings of the AAAI Conference on Artificial Intelligence, Singapore, 20–27 January 2026.

14. Wang, J.; Wang, R.; Zheng, Z.; Lin, R.; Wu, L.; Shu, F. Physical Layer Security Enhancement in AAV-Assisted Cooperative Jamming for Cognitive Radio Networks: A MAPPO-LSTM Deep Reinforcement Learning Approach. IEEE Trans. Veh. Technol. 2025, 74, 4713–4727.

15. Nakra, N.; Pandey, M. Smartphone as an intervention to intention–behavior of patient care. Health Policy Technol. 2019, 8, 383–389.

16. Tusha, A.; Arslan, H. Interference Burden in Wireless Communications: A Comprehensive Survey from PHY Layer Perspective. IEEE Commun. Surv. Tutorials. 2025, 27, 2204–2246.

17. Mobasheri, M.H.; King, D.; Johnston, M.; Gautama, S.; Purkayastha, S.; Darzi, A. The ownership and clinical use of smartphones by doctors and nurses in the UK: A multicentre survey study. BMJ Innov. 2015, 1, 174–181.

18. Zhou, L. Structural contradictions and policy suggestions on generally beneficial childcare service for 0~3-year-old infants and young children in China—Based on statistical data and survey analysis in Hunan Province. Stud. Early Child. Educ. 2023, 51–60.

19. Albanese, P.; Rauhala, A.; Fems, C.; Johnstone, J.; Lam, J.; Atack, E. Hiding the elephant: Child care coverage in four daily newspapers. J. Comp. Fam. Stud. 2010, 41, 817–836.

20. Moreno, C. The 15-Minute City: A Solution for Saving Our Time & Our Planet; John Wiley & Sons Inc.: Hoboken, NJ, USA, 2024.

21. Roulston, K. Analysing interviews. In The SAGE Handbook of Qualitative Data Analysis; Flick, U., Ed.; SAGE Publications Ltd.: London, UK, 2014; pp. 297–313.

22. Schreier, M. Qualitative content analysis—How to do qualitative content analysis? In The SAGE Handbook of Qualitative Data Analysis; Flick, U., Ed.; SAGE Publications Ltd.: London, UK, 2014; pp. 170–184.

23. Erdwins, C.J.; Buffardi, L.C. Different types of day care and their relationship to maternal satisfaction, perceived support, and role conflict. Child Youth Care Forum 1994, 23, 41–54.

24. Hernandez-Leal, P.; Kartal, B.; Taylor, M.E. A Very Condensed Survey and Critique of Multiagent Deep Reinforcement Learning. In Proceedings of the 19th International Conference on Autonomous Agents and Multiagent Systems (AAMAS 2020), Auckland, New Zealand, 9–13 May 2020; International Foundation for Autonomous Agents and Multiagent Systems: Richland, SC, USA, 2020; pp. 2146–2148.