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PRACTICE INSIGHTS

Co-designed Projects in Ecological Research and Practice

Towards effective ecological restoration: Investigating knowledge co-production on fish–habitat relationships with Aquatic Habitat Toronto

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Abstract

1. For decades, the working paradigm for ecological restoration was independent operation of knowledge generators (researchers and scientists) and knowledge users (decision makers and practitioners), resulting in a knowledge–action gap. Knowledge co-production is a collaborative process where research is conducted in a respectful and engaging manner with continuous knowledge exchange and heralded as a means of bridging the divide.
2. Aquatic Habitat Toronto (AHT) is a unique consensus-based partnership with diverse member agencies that engage in restoration ecology and practice along the Toronto Waterfront of Lake Ontario, Canada. Here, we examine the process that AHT uses to enable knowledge co-production and identify associated benefits and challenges.
3. Benefits to AHT's consensus-based partnership include advanced notice of projects, access to diverse expertise and local knowledge, increased understanding of fish habitat, adoption of novel restoration techniques and more effective restoration and improved knowledge exchange, collectively mitigating the knowledge–action divide.
4. Challenges of knowledge co-production facilitated by AHT include consistent agency participation and meaningful engagement, closed or exclusive networks, time commitments and limited financial resources, evolving political landscapes, stability of funding cycles and issues stemming from varying goals and relevancy.
5. Key recommendations for ensuring that knowledge co-production results in actionable science and for maximizing the effectiveness of ecological restoration using AHT's format include securing long-term and stable funding, developing

relationships across agencies and allied partners, engaging early, outlining goals/objectives collaboratively, conducting before and after scientific monitoring, minimizing personal biases, periodically reviewing partnerships to maximize inclusivity, sharing successes (and failures) broadly, and providing open data. AHT embraces an approach that includes integrated planning with multi-jurisdictional support with diverse partners at a tractable scale and we argue that this should be the standard model of aquatic ecosystem management.

KEYWORDS
interdisciplinary, knowledge–action gap, practitioners, restoration ecology

1 | INTRODUCTION

Ecological restoration often involves coordination of diverse organizations and/or agencies (Bissix & Rees, 2001). Despite this, the working paradigm for decades has involved the separation of knowledge generation from action and decision-making (Young et al., 2016). It has been assumed that the work of scientists and researchers would inform decisions by policy and decision makers without formal processes for bringing these groups together (Roche et al., 2021; Young et al., 2013). However, throughout the ecological restoration process, scientific information can be obfuscated when published literature fails to reach the attention of, or is dismissed by, knowledge users resulting in a divide (Sunderland et al., 2009). This ‘knowledge–action gap’ (also variably termed the theory–practice gap and research–practice gap, among others; Cooke, Jeanson, et al., 2021) has been cited by both knowledge generators and users as a hindrance to effective restoration projects (Cvitanovic et al., 2015; Hulme, 2014). Restoration ecology is an applied science, so when studies fail to reach knowledge users or inform management, society experiences a loss and resources are squandered (Cooke, Nguyen, Chapman, et al., 2021). In recent years, there has been an increased focus on producing research that not only advances scientific understanding, but also contributes to practice (Cook et al., 2013; Toomey et al., 2017). One approach that could bridge the gap is knowledge co-production, which is a collaborative, iterative approach to research that involves close coordination between knowledge generators and knowledge users (Nel et al., 2016; Norström et al., 2020). Broadly, the purpose of knowledge co-production is to iteratively join knowing and acting in efforts to address complex social and ecological problems more effectively (Wyborn et al., 2019). Despite the promise of knowledge co-production, it has yet to be mainstreamed and there are few accounts in the literature where co-production has been applied in practice in the realm of ecological restoration.

The Laurentian Great Lakes of Canada and the United States have a long history of anthropogenic degradation stemming from industry, agriculture and urbanization. The Toronto Waterfront, located in the western portion of Lake Ontario, is directly connected to Canada's largest urban centre (5 million people) and has suffered extensive aquatic habitat loss (400 ha; Whillans, 1982). To mitigate negative ecological impacts, the International Joint Commission drafted the Great Lakes Water Quality Agreement, which identified Toronto and Region as an Area of Concern (AOC), along with 43 other degraded areas across the Great Lakes. In 2000, Waterfront Toronto was established to guide and oversee the revitalization and renewal of the area. Around the same time, the Toronto Waterfront Aquatic Habitat Restoration Strategy (TWAHRS; Barnes et al., 2020) was developed to support habitat restoration efforts within the Remedial Action Plan (RAP) area (Barnes et al., 2020). Aquatic Habitat Toronto (AHT) is a consensus-based partnership across various agencies (Table 1), with the primary goals of implementing the TWAHRS and undertaking research via knowledge co-production in support of aquatic habitat restoration.

The goal of this article is to analyse the process of knowledge co-production facilitated by AHT, within an ecological restoration context to mitigate the knowledge–action gap. To do so, we examined the collaboration process among knowledge generators and users, including the benefits and challenges arising from this approach. Ecological restoration activities (i.e. creation/enhancement of aquatic habitat) and supporting processes throughout the Toronto Waterfront are used as a case study to explore the application of knowledge co-production in practice. Consistent with a co-production model, all relevant team members including academic scientists, government scientists, restoration practitioners, and environmental managers are included as co-authors on this paper (Cooke, Nguyen, Young, et al., 2021). Individual perspectives of co-authors were collected and distilled from informal discussions and written contributions during the framing of this paper. Approval from a research ethics review board was not needed given that all participants engaged as full team members and co-authors rather than subjects of the research.

2 | THE CASE

Initiated in 2006, AHT is a consensus-based partnership with the goal of coordinating the implementation of the TWAHRS and managing, enhancing, and protecting waterfront and stream habitats along the Toronto Waterfront. Coordinated by the Toronto and Region Conservation Authority (TRCA), agencies of AHT cover multiple jurisdictional

TABLE 1 Details of partners involved with Aquatic Habitat Toronto, with type of organization, primary roles and jurisdiction

Agency name	Type	Primary role	Jurisdiction
Fisheries and Oceans Canada	Government Department	Policy implementation in support of Canada's oceans and inland waters	Federal
Environment & Climate Change Canada	Government Department	Policy implementation in support of the natural environment and renewable resources	Federal
Toronto and Region Conservation Authority	Agency	Local watershed management and regulator	Toronto
Ports Toronto	Agency	Management of the port of Toronto	Toronto
Ministry of Northern Development, Mines, Natural Resources and Forestry	Government Ministry	Policy implementation in support of mineral and resource sectors, as well as biodiversity and outdoor recreation	Provincial
City of Toronto	Municipal Government	Local administration for the city of Toronto	Toronto
Carleton University	Academic	N/A	N/A
University of Toronto Scarborough Campus	Academic	N/A	N/A

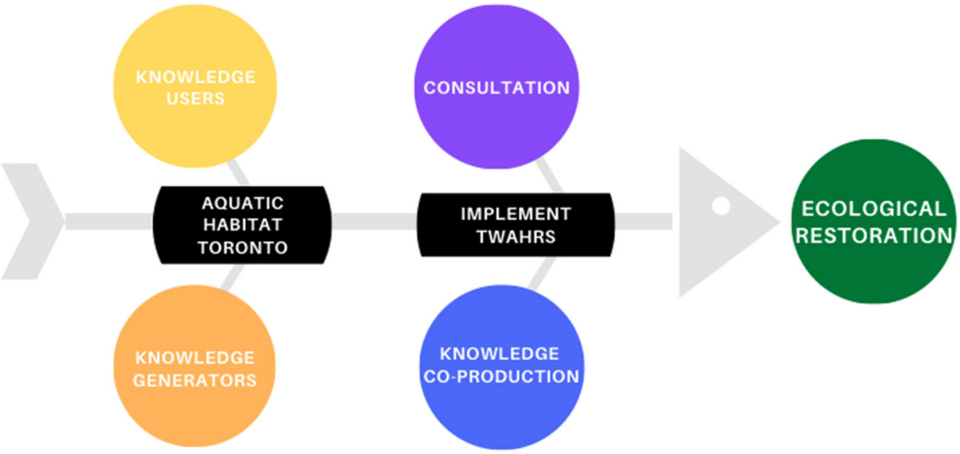

FIGURE 1 Knowledge users (i.e. managers and practitioners) and generators (i.e. academics and scientists) come together to form Aquatic Habitat Toronto (AHT), a unique and diverse partnership that is tasked with implementing the Toronto Waterfront Aquatic Habitat Restoration Strategy (TWAHRS). AHT achieves this collaboratively by consulting with proponents during development or restoration projects and then facilitating knowledge co-production, which then informs ecological restoration.

boundaries and span three levels of government (Table 1). Funding for an AHT coordinator position is derived from Waterfront Toronto and RAP sources, with individual partner agencies providing their time in-kind. Taken together, committee members of AHT include practitioners, scientists, resource managers, and regulators from multiple agencies possessing diverse expertise and contributing varying perspectives. AHT works with proponents on developments throughout all project stages and assists with permitting and approvals. This diverse group supports the planning and implementation of various restoration projects aimed at improving water quality, fish populations, and aquatic habitat conditions. AHT accomplishes this by ensuring proponents are considering aquatic habitat as illustrated in TWAHRS into their project designs or offsetting measures. Additionally, AHT facilitates research via knowledge co-production across diverse agencies to advance actionable science to manage the Toronto Waterfront (Figure 1). Taken together, consultation by AHT and the research it facilitates aims to conserve, offset, restore, and/or create aquatic habitat that has been degraded or destroyed and support decision/policy making.

3 | THE AHT PROCESS: A CLOSER LOOK

3.1 | Consultation: Permitting, design & approvals

The primary AHT objective is to ensure that all waterfront development projects incorporate opportunities to improve aquatic habitat and support sustainable aquatic ecosystems as envisioned in TWAHRS, with efforts ultimately designed to aid the delisting of the Toronto and Region AOC. Specifically, AHT works with proponents of waterfront projects in the early stages to facilitate permitting and approvals processes (i.e. federal and/or provincial approvals dealing with fish habitat, riparian development etc.) across relevant agencies (Figure 1; Table 1). AHT provides a monthly meeting platform for proponents to bring

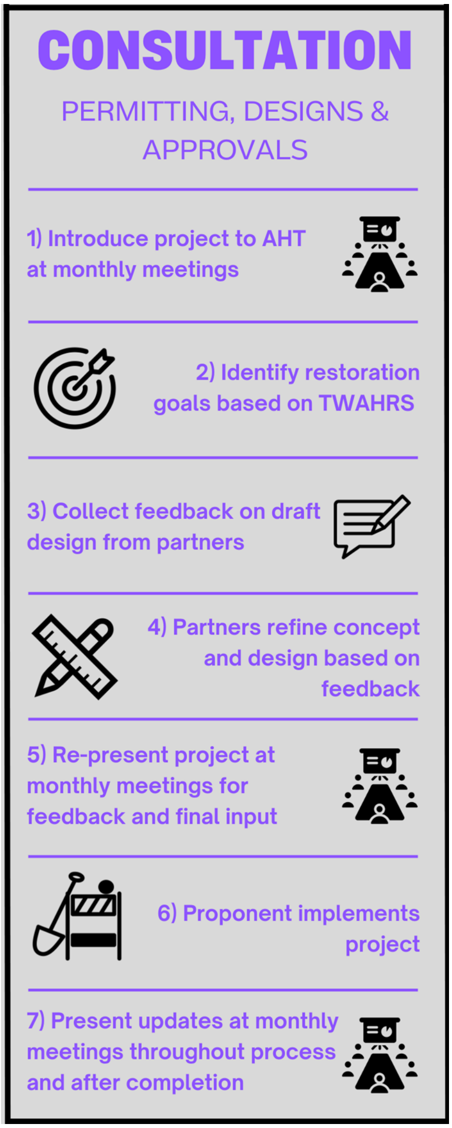

FIGURE 2 Schematic of how consultations proceed within Aquatic Habitat Toronto in support of the primary goal to implement the Toronto Waterfront Aquatic Habitat Restoration Strategy (TWAHRS), while undertaking consultation including permitting, designs, and approvals with proponents

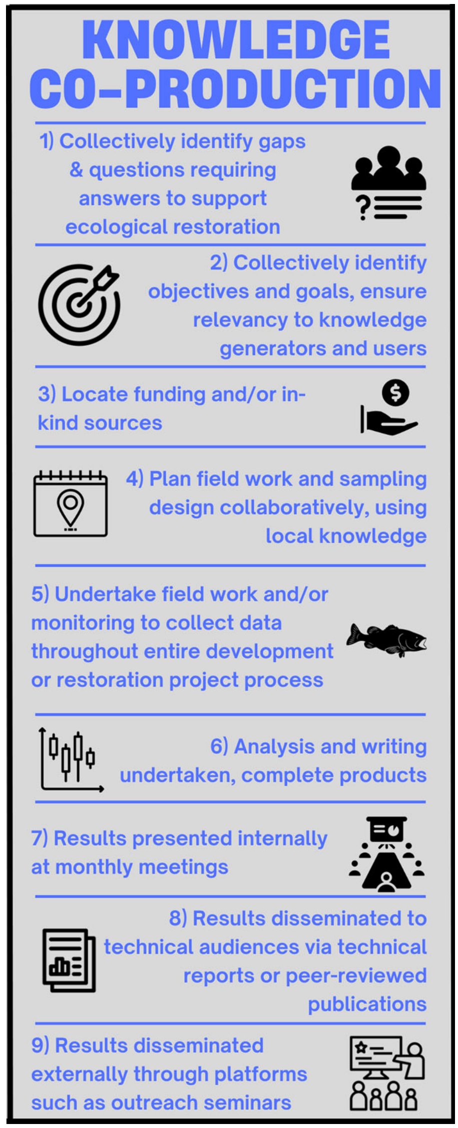

FIGURE 3 Schematic of how Aquatic Habitat Toronto undertakes knowledge co-production to inform habitat design and restoration efforts, as well as to assess efficacy of restoration projects

forward and discuss their projects. At these meetings, feedback and consultation put forward by the committee is derived from diverse expertise and individual experiences (see Figure 2 for detailed process), buttressing findings of scientific research and monitoring enabled by AHT's knowledge co-production.

3.2 | Research: Knowledge co-production

The main goal of the knowledge co-production with respect to research enabled by AHT is to inform habitat design/restoration efforts and to assess the efficacy of restoration projects. Similar to the permitting and design processes, monthly meetings build support for upcoming and ongoing research projects and act as a platform for engagement across agencies (Figure 3). Further, the AHT partners identify the objectives and goals for each study as a group, to maximize relevancy to both knowledge generators and users. In the early stages of knowledge co-production, sources of funding and equipment are identified across members. At monthly meetings, members provide input on sampling design, data collection, and then undertake fieldwork in a collaborative manner. Specifically, AHT coordinates monitoring and scientific research with methods such as acoustic telemetry (Figure 4), as well as electrofishing, trap netting, hydroacoustic surveys, and trawling. To assess efficacy, AHT collects data throughout the entire development/restoration project process: before, during, and post implementation. Once data collection has been completed, analysis and writing are typically undertaken by the lead party (or parties) with results subsequently presented to the rest of the partners at the monthly meetings. Finally, reports and/or peer-reviewed publications

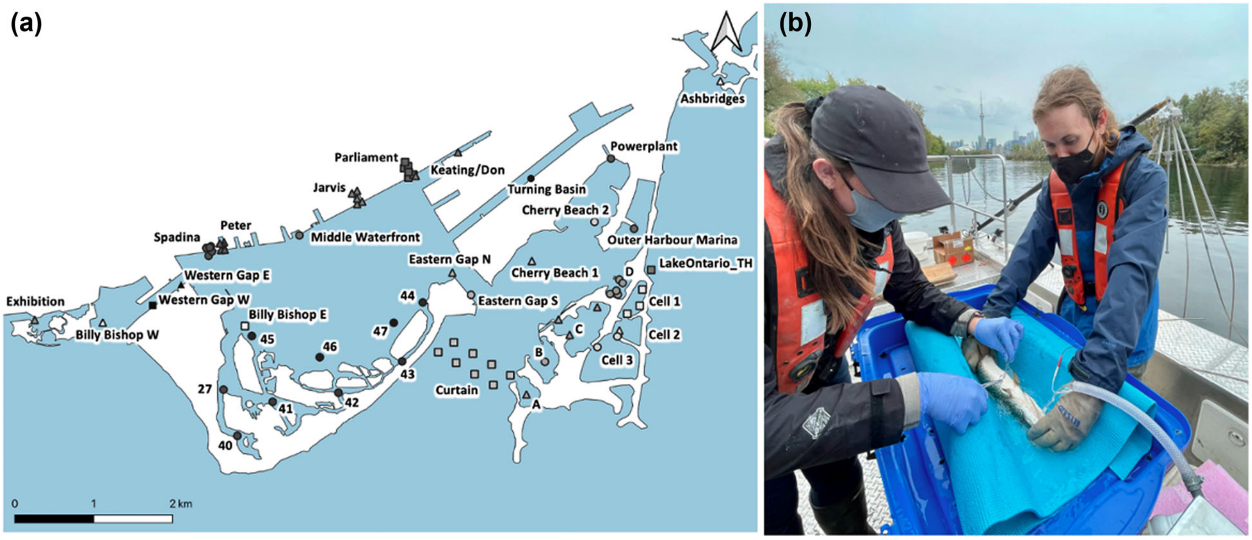

FIGURE 4 (a) Since the initiation of the acoustic array in Toronto Harbour (2010), across 70 receiver stations (which are labelled), over 750 transmitters have been implanted in eight fish species representing different trophic levels, thermal preferences or resource management interests: Largemouth Bass (*Micropterus salmoides*), Northern Pike (*Esox lucius*), White Sucker (*Catostomus commersonii*), Yellow Perch (*Perca flavescens*), Common Carp (*Cyprinus carpio*), Bowfin (*Amia calva*), Walleye (*Sander vitreus*) and Brown Bullhead (*Ameiurus nebulosus*). Acoustic telemetry is one tool used by Aquatic Habitat Toronto when conducting research via knowledge co-production. (b) Northern Pike during surgery to implant an acoustic transmitter

are produced for technical audiences and results are disseminated to external audiences through seminars and public outreach events (Figure 3). It is common for research outputs to include co-authors that span knowledge generators and users (like this paper!). All platforms for engagement both within AHT and beyond to broader audiences play an important role in knowledge co-production by disseminating results, building networks/support, and sustaining momentum of the partnership.

4 | BENEFITS OF KNOWLEDGE CO-PRODUCTION

Relative to the independent operation of knowledge users and generators, AHT's unique approach to enabling knowledge co-production has many benefits which the authors have collectively identified from our joint perspectives. First, since all partners are 'already at the table', AHT permits *Advanced Notice of Projects and Streamlined Multi-Agency Approvals*. In more conventional models, proponents would have to approach partners one at a time (i.e. linearly), thereby slowing the process. AHT's monthly meetings permit early feedback and input on projects from both knowledge generators and users, resulting in a more streamlined process and more time to collaboratively plan and modify designs to benefit fish populations. Further, early and regular engagement across partners results in additional opportunities to increase involvement and success of knowledge co-production (as per Cooke, Nguyen, Chapman, et al., 2021).

In the pursuit of knowledge co-production, AHT's synergies also bring together knowledge generators and users resulting in *Diverse Expertise and Local Knowledge*. Diverse expertise across AHT partners contributes knowledge across different disciplines, lived experiences and viewpoints, which ultimately reduces personal biases (Hulme, 2014). Tapping into practitioner and local knowledge (e.g. local history, fish community dynamics, and other local idiosyncratic elements) at the research design phase enhances project success probabilities (Higgs, 2005), improves the ability to interpret assessments, and broadens support at implementation (Gann et al., 2019). Additionally, incorporating local knowledge derived from knowledge users can inject practicality into habitat design, ensuring that the projects work in 'the real world'.

Research facilitated by knowledge co-production has resulted in an overall *Increased Understanding of Fishes and Fish Habitat*. This has been achieved via long-term monitoring (before, during, and after restoration or development projects), as well as internal data collection and expedited results sharing through the collaborative monthly meetings, technical reports, and peer-reviewed publications (Figure 2). Further, since multiple partners are involved, monitoring, data collection and ecological restoration occur on a larger spatial scale across jurisdictions, promoting ecosystem management at the landscape level (Simberloff, 1998). More thorough understanding of fishes and their habitat requirements with methods such as acoustic telemetry (Lapointe et al., 2013) leads to more targeted investment for evidence-based and data-driven restoration of habitat (Geist & Hawkins, 2016).

AHT's iterative process for knowledge co-production has led to the adoption of *Novel Techniques and More Effective Restoration*. Through knowledge co-production and ultimately, adaptive management, AHT has been able to assess the effectiveness of ecological restoration and novel techniques. For example, habitat restoration at Tommy Thompson Park (see Barnes et al., 2020) found multiple native fish species had high site fidelity at restored areas (Rous et al., 2017), there those restoration techniques will be considered in future projects.

Quite simply, through AHT, there is a direct path between knowledge generators and regulators/practitioners which is exceedingly rare due to the knowledge–action gap. AHT restoration designs are not based on guesses or aesthetics, rather, the iterative process enables continued learning from previous mistakes or successes to increase future optimizations (i.e. it is adaptive management in a restoration context; Murray & Marmorek, 2003).

Finally, AHT-facilitated knowledge co-production results in the *Bridging of the Knowledge-Action Divide by Increasing Knowledge Exchange*. Findings of knowledge co-production can be incorporated into practice sooner because both knowledge generators and users are already in concert, making research more actionable therefore mitigating the knowledge–action gap (Dubois et al., 2020). Because all partners are involved with each stage of knowledge co-production, results are available sooner compared to waiting for the typical publishing process, thus increasing the immediacy of the application (Wright et al., 2020). Due to increased involvement across agencies, there is also increased incentive to take the time to understand and incorporate findings. Additionally, there is decreased time associated with locating and digesting new scientific information, which can be time intensive (Sutherland et al., 2019).

5 | CHALLENGES OF KNOWLEDGE CO-PRODUCTION

Conducting science through knowledge co-production at AHT has many benefits, but it also comes with some challenges. First, effective knowledge co-production within AHT hinges on continuous and consistent *Agency Participation and Meaningful Engagement*. For example, without the regular participation of key agencies to ensure coordinated input at the early planning stages of projects, habitat outcomes and streamlined approvals may be compromised (e.g. agencies revert to reviewing projects independently). This can be fuelled by busy schedules or lack of executive support within a given agency. Further, the type of feedback provided by members of AHT is dependent on who is present at a monthly meeting given that participation is not mandatory. Participation and engagement can also be compromised when a person leaves their role or departs the agency (i.e. staff turnover), resulting in a loss of expertise, as well as institutional and local knowledge, not to mention loss of continuity. Social science research has revealed that collaboration and active participation fosters more actionable science emphasizing the need for consistent engagement (Nguyen et al., 2019). An additional issue regarding participation is the exclusion of historically marginalized groups including Indigenous peoples. Pairing Indigenous knowledge systems with Western science (e.g. restoration ecology) through knowledge co-production can increase knowledge exchange and produce a more thorough understanding of complex problems (Reid et al., 2020).

Despite the benefits associated with consensus-based partnerships (i.e. relationship and trust building), there is often a trade-off leading to a broader dilemma of *Closed or Exclusive Networks*. Further, having a network of partners 'already at the table' and ready to act could potentially bar new partners (i.e. beyond the core group) who may not be invited or are excluded from participation (Connelly & Richardson, 2004). Other important considerations pertaining to inclusion include associated roles of partners, degree of formality or informality during processes, and how collaboration is expected to take place (Young, 2020). This trade-off of 'inclusion and exclusion' is particularly notable when it comes to the exclusion of Indigenous peoples, who have historically been marginalized from participation (Gustafsson & Schilling-Vacaflor, 2022).

Knowledge co-production can also involve substantial *Time Commitments and Financial Resources*. Relative to solo or intra-agency endeavours, the knowledge co-production process involves more time spent in face-to-face meetings (or online meetings) and discussion across partners (Bednarek et al., 2018). Additionally, long-term commitment is required (Nguyen et al., 2019) to not only build relationships, but also because environmental problems involving habitat restoration are complex, often requiring multiple years of data collection (Cooke, Nguyen, Chapman, et al., 2021). Effective knowledge co-production is based on the development of interpersonal relationships and individual investments in goodwill, respect, commitment, and time (Cheruvelil et al., 2014). Personnel time required to participate in the knowledge co-production process is not insignificant, resulting in the use of substantial financial resources from individual agencies and organizations. Other research has also shown that participation in co-production can be draining and stressful for individuals, where they are required to maintain high levels of commitment over time, represent the interests of their groups or employers, and take personal and professional risks in negotiations and decision-making (Young et al., 2020).

Evolving Political Landscapes can also challenge and hinder knowledge co-production. Indeed, lack of political support, shifting political conditions/priorities, or lack of incentives have been cited as causes for project failures in conservation (Catalano et al., 2019). Changes to mandates and funding schemes or priorities within agencies are inevitable, leading to the wax and wane of restoration efforts, research and monitoring opportunities as well as dynamic partner involvement and participation. Additionally, political and legislative landscapes and priorities at the federal, provincial and municipal levels can occur across shorter time horizons, whereas knowledge co-production and restoration are long-term investments in resources and time. On-going support and continued endorsement from each agency are required for participation at meetings and involvement in research.

Changes to *Stability of Funding Cycles* for the administration of knowledge co-production and development of working relationships across agencies can impact the productivity/efficacy of AHT. Further, on-going support via administrative funding is required for AHT to coordinate monthly meetings and disseminate results. Support and funding have been maintained by showcasing the efficacy of AHT as a concept, as well as associated knowledge co-production and restoration projects. Additionally, funding cycles for grants can be misaligned with the time required to develop relationships and engage in knowledge co-production (Cooke, Nguyen, Chapman, et al., 2021).

There can also be challenges that arise concerning *Goals and Relevancy*. Due to the nature of working with diverse partners, mandates

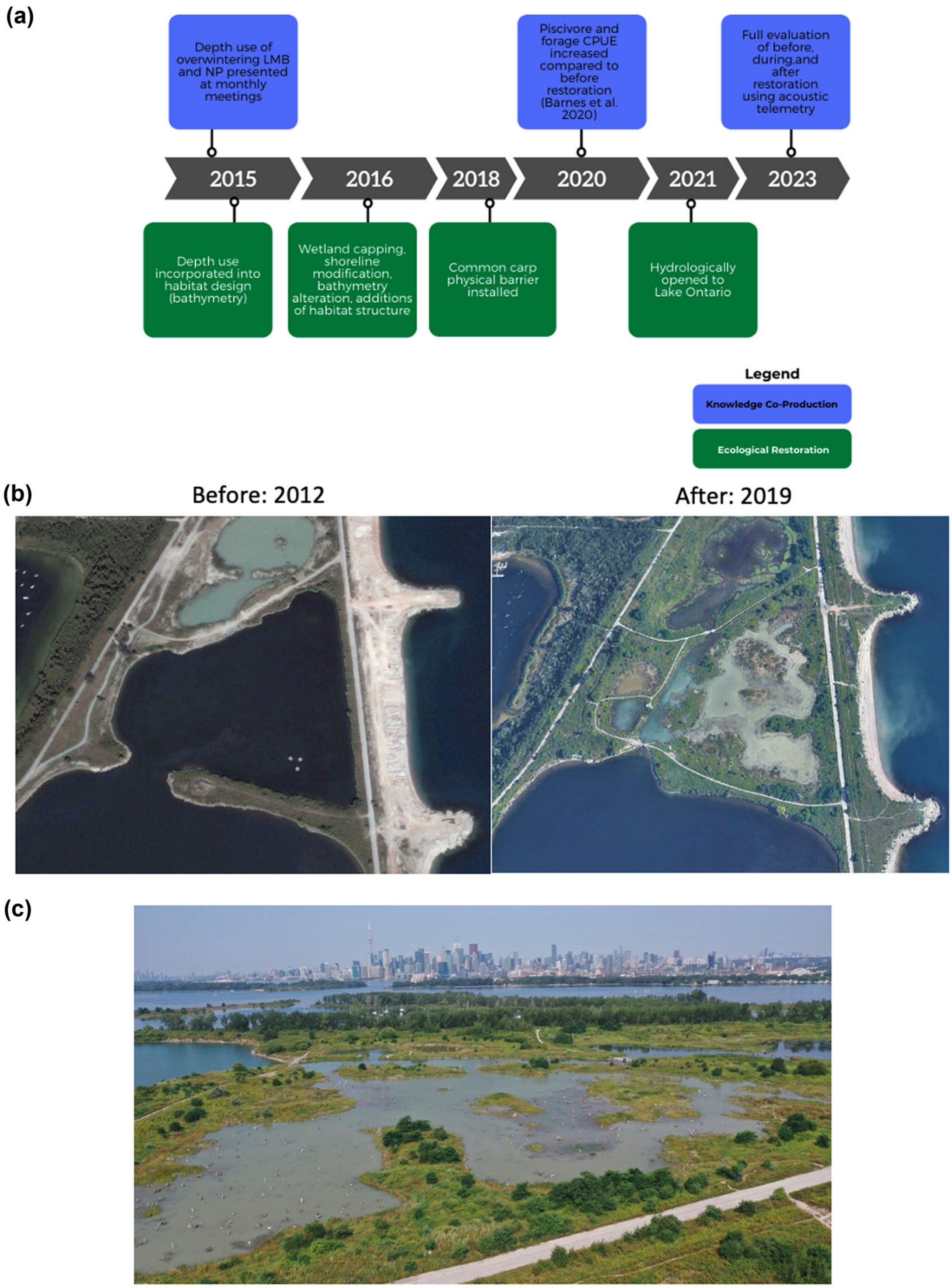

FIGURE 5 (a) Timeline of knowledge co-production (blue) and ecological restoration (green) activities undertaken to complete the restoration of (b) Cell 2 (before and after; Google Earth, 2022) with an (c) aerial view (after). LMB, Largemouth Bass; NP, Northern Pike; CPUE, catch-per-unit-effort. Vegetation planting (ecological restoration) has been continuous since 2016, as well as invasive phragmites (*Phragmites australis*) management.

and objectives can be very different across organizations, leading to varying priorities and competing interests. Multiple partners can make the process of defining success a challenge given competing goals (Geist & Hawkins, 2016). Even during assessments of efficacy, common ground must be found in terms of measures and indicators. Finally, scientific research can be discovery based as opposed to applied, resulting in decreased relevance for practitioners (Arlettaz et al., 2010).

TABLE 2 Recommendations to effectively undertake knowledge co-production and ecological restoration supported by a diverse, consensus-based partnership, such as Aquatic Habitat Toronto

Recommendation	Justification	References
1. Secure long-term and stable funding	Knowledge co-production and ecological restoration are both long-term investments (in terms of finances and time) that can occur across evolving political landscapes, therefore stable funding is required to support agency participation and meaningful engagement.	Bednarek et al., 2018; Nguyen et al., 2019
2. Develop relationships across partners to encourage meaningful engagement	Developing strong relationships early and across partners promotes trust to serve as the foundation for sincere engagement. Further, including a formalized commitment across partners would also encourage continued engagement.	Cooke et al., 2020
3. Engage in knowledge co-production early with diverse partners and many types of knowledge	Initiating knowledge co-production early will maximize time for discussion, feedback, and input throughout the process, ideally resulting in more effective knowledge co-production and ecological restoration. Diverse partners will result in additional perspectives, decreasing personal biases.	Sunderland et al., 2009
4. Outline goals/objectives together and define effectiveness	Collectively identifying goals and objectives will ensure all perspectives are considered and maximize relevance to both knowledge users and generations. Clear benchmarks should be defined prior, to know what success looks like.	Cook et al., 2013; Gann et al., 2019
5. Monitoring should occur before, during, and after developments/projects to maximize understanding of full impacts	Prior to ecological restoration or developments, there should be thorough assessment of current conditions, to not only outline needs and objectives, but to also provide baseline measures for efficacy. Post-project monitoring is crucial to determine success of restoration and learn from mistakes.	Gann et al., 2019; Suding, 2011
6. Ensure knowledge transfer occurs between staff who move on to minimize loss of local knowledge	Local knowledge contributes to improved assessment of efficacies and the identification of bottlenecks. Efforts should be made to minimize loss of local knowledge during personnel transfer.	Gann et al., 2019; Higgs, 2005
7. Periodically review inclusion and participation	To prevent unnecessary exclusion, inclusion and participation should be reviewed to identify and extend invitations to additional partners.	Young, 2020
8. Minimize personal biases during restoration	Relying on results derived from knowledge co-production will decrease personal biases during design and implementation of ecological restoration. Scientific assessments of efficacy should drive which techniques will be used in the future.	Lapointe et al., 2013
9. Share successes (and failures) and information broadly, early, and frequently	Although knowledge co-production can be costly and difficult to implement, disseminating results can demonstrate the usefulness of knowledge co-production as a concept, encouraging vicarious learning, and more collaboration in the future with additional lines of inquiry.	Cooke et al., 2018; Suding, 2011
Share data via open platforms to increase transparency and potential for re-use	Data and knowledge can sometimes be unavailable to knowledge users, furthering the knowledge-action divide, therefore data should be shared openly.	Roche et al., 2021
Integrated planning with multi-jurisdictional support at a workable scale should be the standard model	We argue that diverse multi-agency consensus-based partnerships that facilitate knowledge co-production to support ecological restoration should be that standard model due to myriad benefits.	This paper

6 | ECOLOGICAL RESTORATION IN ACTION: CELL 2 OF TOMMY THOMPSON PARK

Tommy Thompson Park, located in Toronto Harbour, is a human-made peninsula that has undergone extensive ecological restoration guided by TWAHRS. Specifically, there are three cells that have been used as Confined Disposal Facilities (CDF), where polluted dredged material from inner Toronto Harbour was deposited. Deposition in Cell 2 ceased in 1997, and the CDF was subsequently capped with clean soils (2016) to keep the contaminated sediments biologically unavailable (Figure 5a). In 2010, acoustic telemetry studies were initiated and implemented by partners of AHT and results informed the habitat design of Cell 2. Research conducted by Fisheries and Oceans Canada and Carleton University revealed that Largemouth Bass (*Micropterus* *salmoides*) and Northern Pike (*Esox lucius*) overwintered at deeper depths than the original designs for Cell 2 would have provided. These scientific findings were incorporated by the TRCA into revised design plans for Cell 2 by altering the bathymetry to allow for deeper pockets to facilitate survival of these species throughout the winter months. This example of knowledge co-production was instrumental for the application of scientific findings into practice. Additional ecological restoration techniques initiated in 2016 have included shoreline modification, vegetation planting, invasive species management (including *Phragmites australis*) and additions of habitat structure (i.e. logs and various substrate sizes; see Figure 5b,c). Overall, the restoration of Cell 2 has been effective (i.e. increased piscivore and forage catch-per-unit-effort; Barnes et al., 2020); however, these examinations of efficacy have only included data from before and during restoration. Additional studies will be completed in 2023 after Cell 2 is hydrologically connected to Lake Ontario with acoustic telemetry (Figure 5a). This research will also be undertaken by AHT partners using knowledge co-production and aims to advance understanding of ecological restoration efficacy.

7 | RECOMMENDATIONS AND CONCLUSIONS

Knowledge co-production undertaken by AHT has many benefits relative to the independent operation of knowledge users and generators including advanced notice of projects, access to diverse expertise and local knowledge, increased understanding of fish habitat, adoption of novel restoration techniques, and more effective restoration and improved knowledge exchange, thereby mitigating the knowledge–action divide. Challenges associated with the AHT model include consistent agency participation and meaningful engagement, closed or exclusive networks, limited time commitments and financial resources, evolving political landscapes, stability of funding cycles, and issues stemming from varying goals and relevancy.

Based on professional experience with knowledge co-production and ecological restoration, the authors have assembled recommendations (with justifications anchored in the literature) to facilitate knowledge co-production that results in actionable science and to maximize effectiveness of ecological restoration using AHT's format (Table 2). Broadly, we recommend efforts to secure long-term and stable funding, develop relationships across partners, engage early, outline goals/objectives collaboratively, conduct before and after scientific monitoring, minimize personal biases during restoration, periodically review inclusion and participation, share successes (and failures) widely, and provide open data (Table 2). While AHT has been implemented on a relatively small region (i.e. the Greater Toronto Area), knowledge co-production using this model could be conducted at a larger scale by breaking the actors involved into relevant sub-groups to execute different steps within the frameworks. Collectively, we foresee a future where AHT's model for conducting knowledge co-production and ecological restoration is the standard for fisheries science and management. With the knowledge–action gap ever-present and ecological restoration becoming increasingly important as we continue to see habitat loss and degradation in the Anthropocene, it will be critical to maximize efficacy by producing actionable science.

AUTHOR CONTRIBUTIONS

Morgan L. Piczak, Jonathan D. Midwood and Steven J. Cooke conceived the ideas for the manuscript. All authors contributed to writing, with Morgan L. Piczak leading. All authors contributed critically to drafts and gave final approval for publication.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

This manuscript does not use data.

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PEER REVIEW

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