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Freshwater turtle bycatch research supports science-based fisheries management

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Abstract

1. Although it is sometimes difficult for researchers to ensure that their work is used by resource managers to make informed decisions, an example where this knowledge–action gap has been breached is in research published in *Aquatic Conservation: Marine and Freshwater Ecosystems* (AQC) – among other journals – that has assisted fisheries managers in identifying strategies for reducing freshwater turtle bycatch in commercial hoop net fisheries in Ontario, Canada.
2. Research published in AQC has provided evidence towards a simple and effective method for preventing turtle bycatch mortality in hoop nets, which could be adopted by the fishers. Other research published in AQC evaluated the effect of bycatch mortality on the probability of persistence of turtle populations with population viability analyses, and outlined the need to minimize bycatch mortality to prevent local extirpation. Nine other papers have been published on freshwater turtle bycatch in Ontario, furthering our knowledge on this issue including seasonality and temperature effects on catches, other net modifications, post-release effects and assisted recovery, and the perspectives of fishers.
3. The research results were presented to local resource managers with further discussions involving industry and stakeholders to minimize turtle bycatch mortality. Over several years, researchers have provided information to resource managers; however, when an incident of high turtle mortality caught the public eye, the research was readily available and changes in regulations were quick to occur.
4. Reasonably good communication among researchers, resource managers, industry, stakeholders, and the broader public allowed the rapid implementation of regulations to mitigate freshwater turtle bycatch mortality and bridged the knowledge–action gap between researchers and resource managers.
5. Both articles published in AQC had practical conservation impacts and were influential in providing local resource managers with feasible solutions, and the impetus to change regulations. These impacts extended to other jurisdictions and their monitoring programmes, where methods to reduce turtle bycatch mortality were also implemented.

KEYWORDS

catchment management, fish, fishing, lake, littoral, reptiles

1 | INTRODUCTION

It can be difficult for scientists to see whether and how their research is being used to inform the decisions or actions of resource managers. Social science research suggests that when making decisions, resource managers may rely on their professional experiences or outdated and narrowly defined policies, may seek knowledge from other colleagues, or may not have immediate access or the time to read the scientific literature (Nguyen, Young, Corriveau, Hinch, & Cooke, 2018; Pullin & Knight, 2003). Even when managers have access to new information, there can be institutional and cultural barriers to its use (Young, Corriveau, Nguyen, Cooke, & Hinch, 2016). Therefore, there is often a knowledge–action gap (Nguyen, Young, & Cooke, 2017) where the most up-to-date information is not used when making decisions. As a result, more is required of researchers to help disseminate their research to appropriate parties and thus yield positive impacts for conservation (Young, Nguyen, Corriveau, Cooke, & Hinch, 2016). There are very few case studies that document the process of integrating research into decisions and policies because of challenges in gaining access to internal policy documents and discussions, the time lag between research and action, and the potential lack of resources or interest in documenting these processes (Brooks et al., 2018; Krueger et al., 2018). Understanding successful research integration into practice is important and offers lessons learned and insights promoting science-based decisions and policies. Here, we provide an example where science and resource management bridged the knowledge–action gap pertaining to the management of freshwater turtle bycatch in a commercial hoop net fishery in Ontario, Canada. In particular, research published in *Aquatic Conservation: Marine and Freshwater Ecosystems* (AQC) (Larocque, Cooke, & Blouin-Demers, 2012a; Midwood, Cairns, Stoot, Cooke, & Blouin-Demers, 2015), among others, provided important peer-reviewed scientific information to be brought to management and assist with science-based decisions.

The issue of bycatch reduction and survival of discarded fish and other aquatic animals (e.g. reptiles, particularly turtles) is primarily considered in a marine commercial fishery context. Consequently, much of the research on bycatch has focused on marine fisheries; however, freshwater fisheries merit attention as well (Raby, Colotelo, Cooke, & Blouin-Demers, 2011). Passive entrapment gear, such as hoop and trap nets, are used in freshwater commercial fisheries, where turtles incidentally captured in this type of fishing gear may drown (Barko, Briggler, & Ostendorf, 2004; Carrière, 2007; Michaletz & Sullivan, 2002). Turtle populations are particularly susceptible to any increase in adult mortality rates owing to their slow maturation, extraordinary longevity, and naturally high juvenile/hatchling mortality (Congdon, Dunham, & Van Loben Sels, 1993). Adult mortality is especially a problem when species at risk are involved. If adult mortality is high enough in closed populations (such as in an inland lake), extirpation may result (Midwood et al., 2015).

The Lake Ontario Management Unit of the Ontario Ministry of Natural Resources and Forestry (OMNRF) manages the commercial fishery on the Canadian side of Lake Ontario and the St. Lawrence River, including hoop and trap net fisheries. The issue of turtle bycatch and mortality in the hoop net fishery was first documented in 2005 during a radio-telemetry study of common map turtles (*Graptemys geographica*) conducted by a graduate student (Carrière, 2007). With little available empirical information on turtle bycatch from commercial fishing nets at that time, attempting to develop or refine regulations relating to the operation of inland fisheries was difficult. There was a need to better understand freshwater turtle bycatch and to develop mitigation measures associated with inland commercial fishing. Such research can be used to inform management decisions and, specifically, to support recommended changes to gear types (e.g. refinements or new net designs), deployment standards (e.g. time of year, duration of set), and handling techniques to ensure that turtle mortality is prevented to the extent possible.

2 | BODY OF RESEARCH

2.1 | Turtle bycatch occurrence, mortality rates and population viability

Between 2012 and 2017, 11 papers were published regarding turtle bycatch in entrapment fishing gear in Ontario, two of which were published in AQC. One of the first publications assessed the seasonality, composition, and mortality of turtle bycatch associated with commercial hoop net fishing (Larocque et al., 2012). Patterns of seasonality indicated that turtle catches were greater in the spring than the autumn, and turtle mortality could occur in net sets shorter than 48 hours, which is less than the mean net-set duration of 60 hours in the local fishery. This information is important to consider when developing or modifying regulations concerning fishing seasons and gear-set durations. Aside from seasonality, understanding the overall impact of bycatch mortality on turtle populations can further highlight the issue and the need for regulatory changes. Midwood et al. (2015 – in AQC) assessed the population viability of four turtle species that suffer bycatch mortality in the commercial hoop net fishery. Using population size estimates of turtles in a lake where commercial fishing occurs, the increase in annual female mortality levels from bycatch was calculated to be high enough to cause local extirpations within 500 years; however, the time to extirpation varied by species and initial population sizes, with some species predicted to be extirpated in as few as 50 years. Although turtle exclusion devices (further described below) would not prevent all adult females of all turtle species from entering the nets, they would reduce overall turtle captures and were particularly effective for snapping turtles (*Chelydra serpentina*). Similarly, reducing the length of the fishing season would also reduce turtle captures and help prevent mortality. Assessing population effects of additional mortality can provide resource managers with information on whether to support potential regulation changes.

2.2 | Net modifications to reduce turtle catches and mortality

Several papers have been published regarding turtle bycatch rates in experimentally modified hoop nets. Larocque, Cooke, and Blouin-Demers (2012b) compared fish and turtle catch rates in nets fitted with an exclusion device (either vertical bars at the net opening or an exclusion ring at the first funnel of the net) to unmodified nets. Comparisons of fish and turtle escape rates were also made for a net fitted with an escape device (a chimney-like structure that breached the surface of the water for turtles to escape) with a net having a large hole at the top in the cod end of the net. The exclusion devices reduced turtle bycatch, with the exclusion bars working best without affecting fish catches. The escape device allowed painted turtles (*Chrysemys picta*) to leave the net while preventing the loss of fish, unlike nets with a hole. Although all exclusion and escape devices tested were effective at reducing turtle bycatch, further testing on the behaviour of the animals, as well as testing on other turtle species could fine-tune the modifications. A more detailed study on the use of the two exclusion devices used in Larocque, Cooke, and Blouin-Demers (2012b) was conducted by Cairns, Stoot, Blouin-Demers, and Cooke (2013) in which the behaviour of turtles and fish entering the nets was video recorded. Cairns et al. (2013) found that turtles readily turn on their sides to pass through vertical bars at the net entrance. Narrowing the exclusion ring spacing to 5 cm was the best for reducing turtle bycatch of all species potentially encountered while not impeding deployment of gear. However, nets with the smaller exclusion ring were also associated with a 23.4% reduction in target fish catches. Cairns, Stoot, Blouin-Demers, and Cooke (2017) developed and assessed a different escape device based on behavioural trials of turtles in the nets. Cairns et al. (2017) observed multiple turtle species spending more time at the top-anterior portion of the cod-end of the hoop nets (with some species-specific differences). Based on this behaviour, an escape device where turtles pass through a grid and out of an opening at the top-anterior part of the net was developed and tested. This escape device allowed turtles to escape and reduced turtle captures in field trials, but was still associated with an 18% reduction in catch rates of targeted fishes.

The inclusion of floats inside the net is a net modification that does not reduce turtle captures, but instead reduces the mortality of captured turtles. Larocque, Cooke, & Blouin-Demers (2012a – in AQC) assessed the effectiveness of adding floats to hoop nets in reducing anoxia and potential for drowning in painted turtles. Floats were tested in both a controlled setting (short duration sets of 4 hours) as well as when emulating commercial fishing practices in an inland lake (setting in shallow waters and similar net dimensions). Blood lactate (a correlate of anoxia) was higher in turtles from submerged nets compared with nets with floats in both the controlled settings and when emulating fishing practices. Fish captures were statistically similar, although nets with floats had a lower total catch, which may be attributed to the distortion of the net created by the floats when fishing in deeper water. The airspace created by the floats needs to be of adequate size for the turtles to breathe as variation in anoxia was seen within the net sets. Generally, floats were determined to be a viable option for the prevention of turtle mortality in hoop nets.

2.3 | Attraction of turtles to nets

Dead fish in nets may be an attractant for turtles, thus providing another reason for checking nets more frequently and reducing the chances of fish mortality and ensuing turtle catches. Larocque, Watson, Blouin-Demers, and Cooke (2012) determined whether dead fish were an attractant to turtles by comparing catches in hoop nets with 1-day deceased fish, 5-day deceased fish, and no fish. Although there were no differences in turtle or fish catch rates among treatments, water temperature as a covariate in the study indicated that more turtles were captured when the water was warmer. As water temperatures warm in the spring, it further increases the risk of turtle capture in nets and subsequent mortality.

2.4 | Post-release effects and recovery of turtles submerged in nets

If turtles are captured in hoop nets, can anything be done to promote their recovery? LeDain et al. (2013) monitored the ability of painted turtles to recover following prolonged submergence in hoop nets using both blood physiology and reflex impairment measures. To help turtles recover from anoxia due to submergence in nets, turtles were either placed on a floating platform or in the water to recover for an hour. Blood physiology had not returned to baseline levels after an hour for either treatment; however, reflexes were less impaired for turtles kept out of water than for those in water, indicating better recovery out of the water. Thus, bringing submerged turtles on shore will promote recovery if the turtles have impaired reflexes upon removal from a net. Building upon the use of blood physiology and reflex impairment measures, Stoot, Cairns, Blouin-Demers, and Cooke (2013) assessed how sex and species of turtle influenced the consequences of being submerged in nets. All groups were similarly affected, as measured by blood physiology; however, eastern musk turtles (*Sternotherus odoratus*) showed less reflex impairment than the other species, probably owing to their better ability to take up oxygen from the water. The reflex impairments proved to be a good indicator of sub-lethal impairment for multiple turtle species when evaluating consequences of different fishing practices.

Aside from sub-lethal impairment, post-release mortality and altered behaviour may potentially be an issue with turtles after being submerged in nets. Gutowsky et al. (2017) assessed post-release behaviour and survival using biologgers with painted and eastern musk turtles from two treatment groups (entrapment for 4 hours and a control). No post-release mortality was observed. Within the first

6 hours after release, turtles submerged in nets moved less than the controls, and their vertical distribution and thermal habitat use differed in the first 2 hours after release. By 48 hours post-release, both groups had similar activity levels, indicating that the submerged turtles had recovered.

2.5 | Fishers' perspectives on freshwater turtle bycatch

Considering the perspective of the fishers on the issue of turtle bycatch can help understand their point of view, but also assist resource managers in finding agreeable (i.e. socially robust) solutions to the problem. Nguyen et al. (2013) conducted phone interviews with the fishers in the commercial hoop net fishery to better understand their stance on turtle bycatch, conservation, and strategies to reduce bycatch. Generally, all the respondents had encountered turtles in their nets; however, turtle bycatch varied regionally, seasonally, by habitat and depth, and resulted in varying perspectives on turtle bycatch. Turtle bycatch was not seen as a conservation issue by the fishers, resulting in negative feedback regarding the use of bycatch reduction devices. Interviews with fishers highlighted practical issues with the use of modified nets such as the vertical bars being too heavy, attaching an escape chimney to the net could lead to entanglement of gear, and floating devices could potentially attract muskrats that chew and damage their gear. There was a wide array of opinions among fishers, resulting in some already adopting methods to deal with turtle bycatch, whereas others had apprehension of potential changes to the fishery. Understanding stakeholders' opinions on the matter is useful for resource managers to help identify solutions that would be palatable to fishers, while allowing them to voice their thoughts and increasing the legitimacy of the research (Cash et al., 2003; Posner, McKenzie, & Ricketts, 2016). Furthermore, identifying allies among fishers to champion conservation tools can help promote their use.

3 | IMPACTS ON POLICY AND MANAGEMENT

The OMNRF is responsible for the licensing, monitoring, and enforcement of the commercial fishery in Ontario. When developing regulations, multiple factors are considered: effectiveness of the regulation to achieve the desired level of protection/sustainability of the resource, the impact of the regulation on the fisher's ability to fish effectively, the expectations of the public and other stakeholder groups, and the enforceability of the regulation. Although the fishers and the Ontario Commercial Fisheries Association (OCFA) want to be recognized as good stewards of the resource, and be part of a sustainable industry that provides a quality product to the people of Ontario, they do not want a regulatory structure that is overly prescriptive and onerous to comply with.

Freshwater turtles in Ontario are considered at risk. At present, all but one (midland painted turtle) of the eight turtle species in Ontario are listed as species at risk in the province (O. Reg. 230/08). All eight species are listed federally under the Committee on the Status of Endangered Wildlife in Canada as part of the Species at Risk Act (SARA), of which six are also listed under Schedule 1 of SARA. From a regulatory standpoint on encountering a species at risk, Ontario's Endangered Species Act (O. Reg 242/08) prohibits the 'harassing, capturing or taking' of Endangered Species Act-listed species. However, the incidental capture of these species is permitted by licensed commercial fishers who are fishing in accordance with the conditions of their permit. Although the incidental capture is not illegal, it is concerning that the most commonly encountered turtle in hoop nets in the management zone is a SARA-listed species (northern map turtle; C. Lake, personal communication, September 2019) which, incidentally, is the same species found dead that brought the bycatch issue to light in 2005. Thus, it is primarily a conservation issue (and less of a regulatory issue if conditions of the licences are being followed) when species at risk are being incidentally killed.

As noted above, research conducted in Ontario inland lakes using entrapment fishing gear has resulted in the publication of 11 scientific papers on the issue of turtle bycatch, pertaining to the hoop net fishery. Although this research is applicable to other areas and scenarios, it is most relevant to the management efforts being made to mitigate the issues associated with turtle bycatch in freshwater commercial fisheries. The research and publishing processes take time, however, and the research team was proactive and prompt with communicating and disseminating results to local resource managers and stakeholders via presentations at meetings. Meetings took place between 2011 and 2012 involving university researchers and the OMNRF, and one meeting also included the fishers and the OCFA. It was at these meetings that research pertaining to net modifications (exclusion and escape devices, as well as floats in nets to prevent turtle mortality – research published in AQC) and seasonality/temperature factors were discussed. Certain potential regulation changes (e.g. 24-hour net sets in warmer months) were not deemed feasible by fishers. Given the diversity of the fishing conditions and scenarios that could result in turtle bycatch, resource managers designed best fishing practices based on published research combined with the commercial fishers' decades of experience to reduce turtle mortality. Thus, the Lake Ontario Commercial Fishers Voluntary Biodiversity Protocol was introduced and unanimously accepted by fishers in 2013 (OMNRF, 2015). Following this protocol, commercial fishers voluntarily adopted best management practices to reduce turtle mortality including five key actions; (i) adding turtles to existing mandatory Daily Catch Reporting requirements; (ii) data collection; (iii) turtle bycatch mitigation measures; (iv) cooperation; and (v) continuous improvement). At the same time, the OMNRF audited the effectiveness of floats in hoop nets and other mitigation techniques used by the commercial fishers (OMNRF, 2015). The research conducted and communicated to resource managers and stakeholders

resulted in practical measures being taken to help reduce turtle bycatch.

Commercial fishers were now responsible for using best practices for reducing turtle bycatch through a voluntary, non-legally binding Lake Ontario Commercial Fishers Voluntary Biodiversity Protocol. As a voluntary programme, the industry relied on the due diligence of its members to take measures to minimize turtle bycatch. However, Nguyen et al. (2013) indicated that there was resistance from commercial fishers to report turtle bycatch in the Daily Catch Records, which could result in unreliable data for informing resource managers on the prevalence of bycatch. Commercial fishers have mixed opinions regarding reporting. There is fear of regulatory changes and impacts to their livelihoods from reporting, uncertainty of why turtle conservation is an issue and the necessity to report, and a desire to maintain a sustainable fishery and reporting properly (Nguyen et al., 2013). Some fishers had already adopted their own methods of reducing turtle mortality using beach balls to create air pockets in their nets, but there was still resistance to net modifications (Nguyen et al., 2013). During the first few years when commercial fishers were self-managed regarding turtle bycatch, the OMNRF inspected some of the nets. Although sample sizes were small, the presence of floats in nets (only 28% of nets audited had floats) was found to have a positive effect on captured turtles, and turtle catches were reduced when nets were set deeper (OMNRF, 2015). The OMNRF continued to review research supplied by academics to make informed decisions on the situation. By 2015, mitigation seemed to be working and the voluntary measures were left in place but were not evaluated closely after the initial focused monitoring.

The industry's voluntary self-management of reducing turtle bycatch mortality is effective when all individuals are acting responsibly. In the spring of 2018, however, the issue of freshwater turtle bycatch needed to be revisited. Approximately a dozen dead turtles (snapping turtles, painted turtles, northern map turtles) were found near a commercial fisher's net near Kingston, Ontario. The environmental organization Turtles Kingston brought this to the attention of OMNRF and reported this instance on a social media newsletter, bringing more public awareness to the situation. Turtles Kingston consulted published literature by several of the authors of this paper (Larocque, Midwood, Nguyen, Blouin-Demers, Cooke), including in journals such as AQC, to articulate more fully their concerns and even offer some suggestions of gear modifications. In response to the incident, OMNRF held meetings with fishers and OCFA summarizing the results of the Daily Catch Records over the past 5 years. The variability and trends in turtle catches was evident in the Daily Catch Records; however, reporting accuracy may not be equal across all areas. Fishers were reminded of existing licence conditions, and the importance of maintaining good public relations, prompting the OFCA to recommend a meeting with the environmental organization. In early February 2019, a meeting was held between representatives from OMNRFs Lake Ontario Management Unit, OCFA, Turtles Kingston, and two commercial fishers, so that all parties could better understand each other's concerns and communicate directly with each other. The voluntary best practices of fishers to reduce turtle bycatch mortality was no longer sufficient to address public concerns and regulatory changes were needed. Upon considering the research, reviewing the trends in Daily Catch Records, and assessing the use of floats in trap-net monitoring programmes, resource managers came up with a solution. By 1 May 2019, licences were changed to include situation-dependent conditions in which best fishing practices were now mandated and no longer voluntary. Fishers were still given the flexibility to modify their fishing techniques (e.g. set for shorter duration or use floats in nets in shallow waters), so that they could find a solution that worked best for their particular situation, taking into account the likelihood of encountering turtles in a given area and their respective fishing methods, gear type,s and net-lift times. Fishers were given multiple options to comply with the new turtle bycatch mitigation conditions of their licences. The fishers were not pleased with the negative attention that this specific incident of turtle mortality created for their industry and were generally receptive to the changes. Monitoring of the fishery continues, and the measures used to mitigate bycatch may be modified if necessary.

4 | TIMELINE FOR EFFECTIVE CHANGES

After the turtle bycatch mortality incident in 2005, turtle bycatch management efforts were initiated by OMNRF in 2007, and the issue was revisited periodically over the next decade, until the more recent focus on the issue in 2018. It should be noted that turtle bycatch is just one of many aspects of the commercial fishery that OMNRF manages: quota management and allocation, adjustment of fishing seasons, gear regulations, fish community assessment, and fisheries enforcement are all areas that require planning and discussion, and all take time. From a research and academic perspective, progress was slow at first to find solutions for management – securing funding, conducting research, publishing, and finally communicating results to resource managers takes time, and primarily occurred in 2011–2012, roughly 6–7 years after the incident of turtle mortality in 2005 was discovered. Once the initial research had been published, the researchers engaged with the resource managers (OMNRF – Lake Ontario Management Unit) and industry (OCFA), and changes were made. By 2013, the voluntary best fishing practices were adopted by the industry, 1 year after discussions with academics. Some fine-tuning (reiterating the use of floats in shallow nets, updates on the academic research) and monitoring occurred for a few years; however, when concerned citizens became involved and notified resource managers in 2018 about finding turtles at risk dead near nets, the information needed to make quick and effective changes to the regulations was readily available. In less than a year, discussions occurred and in a matter of months regulatory changes were enacted to help resolve the situation. The acceleration of the recent changes was the result of adequate communication between all parties, and a desire by all parties to find common ground. Management had

been informed by academics, heard the concerns of citizens, and discussed openly with the industry solutions that would not unduly affect their livelihood while mitigating turtle bycatch mortality.

5 | PRACTICAL IMPACTS OF PUBLICATIONS IN AQUATIC CONSERVATION

Additional practical impacts have resulted from this research, in particular the two articles published in AQC. Larocque, Cooke, and Blouin-Demers (2012a) provided evidence that the use of floats in passive nets is an easy and effective method for reducing turtle mortality without affecting fish catches, especially when sampling in wetlands where turtles are more abundant. Not only were the results applicable to the hoop nets used in the study, but also to other styles of passive gear, such as fyke and trap nets. The lead author of the paper has received emails from other government agencies (e.g. throughout the USA) who, after reading the paper, adopted the use of floats as a measure to mitigate turtle mortality associated with passive fishing gear. The OMNRF has also adopted the use of floats in their trap nets in fish community assessments, starting in 2013, and continuing through the 2018 season. Evaluation of this fisheries-independent fish community assessment programme, and the results of the use of floats on fishability of trap nets will provide more insight on the management of bycatch in the commercial fishery. Although adding floats to nets is a relatively simple solution for reducing turtle mortality, it was important also to determine whether fish catches were adversely affected and this was accomplished through the research described in Larocque, Cooke, and Blouin-Demers (2012a). Knowing that fish catches are not significantly reduced by floats is particularly important for long-term monitoring programmes run by agencies prior to adopting any changes to their methods. The positive feedback received from Larocque, Cooke, and Blouin-Demers (2012a) and the changes it has evoked to further improve turtle survival are very promising.

Another practical impact of this bycatch research is the study by Midwood et al. (2015), which increased awareness of the severity of the loss of small numbers of adult female turtles and how it can lead to population extirpations if left unchecked. Furthermore, Midwood et al. (2015) assessed the population-level impacts of potential regulatory changes from seasonal closures and net modifications (e.g. similar to those outlined in Larocque, Cooke, & Blouin-Demers, 2012b) – providing more evidence for resource managers to use when making regulatory changes. This study provides further impetus to reduce turtle bycatch mortality, not just with the Ontario fishery specifically but everywhere that freshwater turtles may be inadvertently captured and killed in nets. For example, Midwood et al. (2015) was cited by Environment Canada's proposed management plan for northern map turtle, reinforcing the importance of considering bycatch when planning the recovery of a species (Environment Canada, 2016).

6 | SCIENCE AND RESOURCE MANAGEMENT WORKING TOGETHER

Addressing the concerns of turtle bycatch mortality in the Lake Ontario–St. Lawrence River commercial fisheries required good communication and willingness among researchers, resource managers, industry, stakeholders, and the broader public. Research published in AQC (among other journals) communicated details about the topic and aided in resource managers' decisions. Beyond publications, the proactivity of researchers and willingness to find solutions by all parties are important for mobilizing the published research into actions (Nguyen, Young, Brownscombe, & Cooke, 2019). Resource managers held discussions among all involved parties to ensure that outcomes reflected a balance in which the fishery can be operational while also preventing the mortality of freshwater turtles. This process increases the legitimacy (i.e. unbiased and considers multiple viewpoints) of knowledge produced, which has been shown to increase its impact (Posner et al., 2016). Originally, it took time for research to provide information to resource managers; however, when the incidence of high turtle mortality became public in 2018, the research was readily available and the time required for regulation change relatively short. In retrospect, the first step in the research programme should have been the human dimensions study (Nguyen et al., 2013) as it could have helped to focus empirical research efforts and identify industry champions to work with (i.e. fishers who have developed their own techniques for reducing the mortality from turtle bycatch).

Although there was some level of communication with resource managers and commercial fishers during the research, a co-production model (Nel et al., 2016) or co-assessment model (Sutherland, Shackelford, & Rose, 2017) would have been valuable and would probably have led to faster uptake of findings (e.g. see Bojórquez-Tapia, Pedroza, Ponce-Díaz, De León, & Lluch-Belda,- 2017 for a co-production example with sea turtle bycatch reduction). The existing literature published by several of the authors of this paper (Larocque, Midwood, Nguyen, Blouin-Demers, Cooke) has informed the decisions made by resource managers over the past decade in Ontario, as well as provided information and context to environmental groups concerned with resource management issues. The papers published in AQC have also been influential in other jurisdictions and their monitoring programmes to reduce turtle mortality (e.g. uptake of floats in nets) as well as providing evidence of the severity of adult female turtle mortality and how it can lead to extirpations. It is likely that including population-level information has helped the uptake of research, as many cited barriers of integrating fisheries research into management included problems with small sample sizes, individual information, and mismatch in scales of research and management needs (Nguyen et al., 2018; Young, Nguyen, et al., 2016). Here, we have provided evidence of bridging the knowledge–action gap and an example of how our research published in AQC (and other similar journals) has had a positive impact on the conservation of freshwater turtle species.

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