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REVIEW ARTICLE

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Interactions between inland water-based recreation and freshwater turtles: A review

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Abstract

1. Outdoor recreation brings countless benefits to humans. Understanding the inevitable human interactions with nature is essential for conserving the outdoors for years to come. Water-based recreation in freshwater ecosystems is increasing in popularity, but freshwater biodiversity is in global decline.
2. The aim of this review is to explore the interactions between water users and freshwater turtles during inland water-based recreation.
3. Thirty articles (most based in North America) were found to study human–turtle interactions during water-based recreation, 29 of which reported water-based recreational activities posing negative effects on freshwater turtle populations. Negative, direct effect interactions included boat collisions with turtles and accidental hooking of turtles with fishhooks. Negative, indirect effect interactions included human presence near habitats used by turtles and wake action with subsequent shoreline erosion. One article reported a positive interaction between humans and freshwater turtles when installing a non-disruptive turtle observation deck.
4. Eleven articles discussed conservation measures to mitigate turtle risks during water-based recreation, but none evaluated their efficacy. Conservation measures included regulating boat types, sizes and access points, protecting habitats used by turtles, designating 'no wake' boating zones, restricting fishing permits, installing turtle basking perches, promoting public awareness and outreach and implementing participatory science and stewardship programmes.
5. Future research on human–freshwater turtle interactions during inland water-based recreation could explore the efficacy of conservation measures, potential interactions outside of regularly studied boating and fishing activities and recreation-induced turtle habitat alterations. Also, future research could explore the human dimension side of human–turtle interactions, including perceptions and knowledge from water users on the interactions they experience, and their awareness and actions of pro-environmental behaviours to protect turtles during water-based recreation.

KEYWORDS
conservation, freshwater, human–wildlife interaction, outdoor recreation, turtle, water-based recreation

1 | INTRODUCTION

Outdoor recreation, or nature-based recreation, involves direct and indirect interactions between humans and nature. Many benefits arise from these human–nature interactions. For humans, outdoor recreation can enhance physical and mental health (Thomsen et al., 2018), rejuvenate spirituality and cultural identity (de Groot et al., 2010) and provide a sense of community (Breunig et al., 2010). Bi-directional interactions also provide benefits to nature. Outdoor recreation promotes environmental stewardship (Miller et al., 2020), encourages individual pro-environmental behaviours and attitudes (Thapa, 2010; Vaske & Kobrin, 2001) and offers opportunities for science education (Lugg, 2007). Also, outdoor recreation may lead to economic benefits, including admission fees and recreation licences providing funding for regional conservation (Green & Donnelly, 2003), as well as recreational tourism activities supporting businesses in surrounding communities (Bergstrom et al., 1990). During outdoor recreation, it is crucial that interactions between people and nature occur in a sustainable manner, so both parties can continue experiencing these benefits.

Inland water-based recreation refers to activities such as swimming, recreational fishing, boating, kayaking and water skiing (Vesterinen et al., 2010) on inland aquatic systems such as rivers, streams, wetlands, reservoirs and lakes (Fergus et al., 2017). As a result, human interactions with components of these systems, such as wildlife, are inevitable and sometimes necessary during recreation (e.g. recreational fishing). Yet simultaneously, freshwater biodiversity is declining at a global scale owing to human activities (Dudgeon et al., 2006; Reid et al., 2019). For example, Europe reported in 2015 that impacts from water-based recreational activities are the fourth greatest threat to freshwater ecosystems (Graf et al., 2015). Still, trends on regional freshwater wildlife affected by inland water-based recreation remain overlooked (Venohr et al., 2018). As such, studying human–wildlife interactions in recreation may be a key step towards developing more effective protection and management practices for inland water-based recreation.

Inland water-based recreation can overlap substantially with habitat used by freshwater turtles, and freshwater turtles are threatened with extinction (Rhodin et al., 2018). Freshwater turtle populations are sensitive to human impacts owing to their life history traits, including delayed sexual maturity, low fecundity and long generation times (Congdon et al., 1993; Howell et al., 2019). Understanding potential effects turtles face from human recreation is important as a small increase of 2% in adult mortality from anthropogenic effects may limit turtle population growth (Spencer et al., 2017). Further, turtle hatchling survivorship is low (0.01% in some cases), and thus, the loss of a few adult female turtles may jeopardize the population as there would be fewer females contributing to population growth (Galois & Ouellet, 2007). Freshwater turtles have both ecological and cultural significance (Lovich et al., 2018), which emphasizes the need for immediate and stronger protection for turtle populations, especially when faced with deleterious human impacts.

As water-based recreation increases in popularity, there is a greater need to explore the relationship between humans and freshwater turtles in these environments to inform protection strategies for turtle populations. In 2019, the annual average sales of recreational boats increased by 5% in Canada (NMMA, 2020a) and by 12.5% in the United States of America (USA) (NMMA, 2020b). Current research for human impacts on turtles mainly focuses on hunting freshwater turtles (Browne et al., 2020; Walter, 2000) or land-based interaction of roadside mortality (Carstairs et al., 2018; Steen et al., 2006). Although it is known that turtles are one of the most endangered taxa (Cox et al., 2022; Stanford et al., 2020), there are still limited syntheses on freshwater turtle disturbances especially in the context of inland water-based recreation. Literature on human impacts in recreation mostly focuses on negative human disturbances (Bowen & Janzen, 2008). Identifying interactions between humans and freshwater turtles that have a positive effect will further encourage evidence-based solutions catered to human recreational activities, rather than resorting to general protection practices applied to these areas. For example, engaging recreational fishers in regional conservation projects has led to protection of fish populations at risk, including improving fish migration barriers and monitoring fish recruitment success (Granek et al., 2008).

This article reviews the interactions between incidental water-based recreational activities and freshwater turtles. The research objectives to address this goal were as follows:

1. Characterize interactions between freshwater turtles and water-based recreational activities.
2. Summarize the mitigation efforts used to minimize effects of water-based recreation on freshwater turtles and their effectiveness at protecting these populations.
3. Identify research gaps when reporting on interactions between humans and freshwater turtles during inland water-based recreation.

This literature review focused on incidental impacts of water-based recreational activities on turtles and excluded articles that are outside of this scope, such as hunting turtles or roadside mortality.

2 | METHODS

An a priori methods protocol was developed to minimize biases throughout the data collection process (Supporting Information, Data S1). Below are the summarized a priori methods and any deviations from these methods.

2.1 | Searches for articles

Articles were not restricted on publication year or geographical location but were limited to English language only. After compiling relevant benchmark articles that were key articles in the field discussing water-based recreation and freshwater turtles ($n = 10$; Supporting Information, Data S1), and conducting trial searches, the finalized search string was as follows: ('freshwater turtle*' OR 'aquatic turtle*') AND (recreation* OR human* OR activit* OR water-based OR shore-based).

Searches included both peer-reviewed articles and grey literature and were performed on Web of Science (Core Collection), Scopus and Google Scholar databases. For Web of Science and Scopus, searches were conducted on document title, abstract and keywords. For Google Scholar, searches were conducted on titles rather than full-text to capture more grey literature (Haddaway et al., 2015). The review deviated from the protocol to also include relevant articles recommended by a herpetology researcher with expertise in human–turtle interactions during water-based recreation. This expert provided articles that were not captured in the search or were published at the time of the review synthesis.

Full text of all articles were retrieved by Carleton University subscriptions and inter-library loan services. When the full text was not found through subscriptions or inter-library services, articles were further sought for retrieval by searching ResearchGate, Google and by contacting the author(s).

2.2 | Article screening and data extraction

Compiled articles from searches were screened for relevance on Covidence (Veritas Health Innovation Lt), a systematic review management tool that allows reviewers to import and independently screen articles at title and abstract and at full text. Articles were included if they discussed both of the following eligibility criteria: (1) inland water-based recreation and (2) human–freshwater turtle interaction (Supporting Information, Data S1). The first eligibility criterion on inland water-based recreation was defined as human activities (e.g. boating, angling and swimming; Vesterinen et al., 2010) on inland freshwater systems (e.g. rivers, swamps and reservoirs; Fergus et al., 2017). The second eligibility criterion on human–freshwater turtle interactions was defined as discussion of human direct or indirect interactions with freshwater turtles and/or discussion of freshwater turtle management or mitigation efforts during water-based recreation. For the second eligibility criterion, articles were excluded if they only discussed freshwater turtles, such as focusing only on biological aspects of turtles (e.g. neurobiology of turtles and hibernation patterns).

Included articles were uploaded to NVivo 14 (version R1.6, Lumivero), a qualitative data analysis software. NVivo allowed for article data extraction, where quotes from text were highlighted and coded into categories. Data extraction categories included target study species, country, data collection methods, type of human–turtle interaction, mitigation efforts and research gaps. However, the review deviated from the a priori protocol with later extracted data on target study species, country and data collection methods conducted in Microsoft Excel for ease of bibliometric analysis across articles.

An inductive approach was used to categorize data collection methods in the articles included (Thomas, 2006). Quotes on data collection methods from the articles included were extracted in Microsoft Excel during the data extraction phase. The type of data collection methods used was identified in each extracted quote. Then, similar types of data collection methods were grouped into broader, more structured types for comparison across articles (Data S2). In total, 12 types of data collection methods were used across the included articles and classified as either (1) turtle data collection method or (2) human data collection method. Because all included articles discussing human–freshwater turtle interactions, the distinction between turtle data collection method and human data collection method identified whether turtle data, human data or both were collected and analysed to study these interactions.

3 | RESULTS

Searches were conducted until 23 January 2023, which resulted in 646 articles after duplicates were removed (Figure 1). A herpetology expert (GB) recommended three additional articles based on eligibility criteria on 11 June 2023. Article title and abstracts were screened with eligibility criteria and resulted in 50 articles deemed eligible for further screening at full text. After 50 article full texts were screened, a total of 30 articles were included for data extraction and analysis (see Supporting Information, Data S2 for list of excluded articles with reasoning and list of included articles).

Out of the 30 articles included, 28 were peer-reviewed journal articles, and two were grey literature. The publication year of included articles ranged between 1995 and 2023, with gradual, annual linear growth. Most articles included were published within the last 10 years ($n = 23$, 77% of articles), with the greatest annual number of articles published in 2022 ($n = 4$).

Most studies included were from the United States of America (USA) ($n = 22$), followed by Canada ($n = 8$), then Italy ($n = 1$). In one instance, a study focused on freshwater turtles in a water body that spanned geopolitical borders (Lake Champlain between Québec, Canada and Vermont, USA; Galois & Ouellet, 2007), and this was accounted for in the total article count per country.

3.1 | Turtle species and data collection methods

Twenty freshwater turtle species were studied across the 30 articles included (Table 1). The most studied turtle species were painted turtles (*Chrysemys picta*, $n = 10$) and pond sliders (*Trachemys scripta*, $n = 10$), whereas the most studied turtle genus was map turtles (*Graptemys*, $n = 12$). According to the International Union for Conservation of Nature (IUCN) Red List of Threatened Species, out of

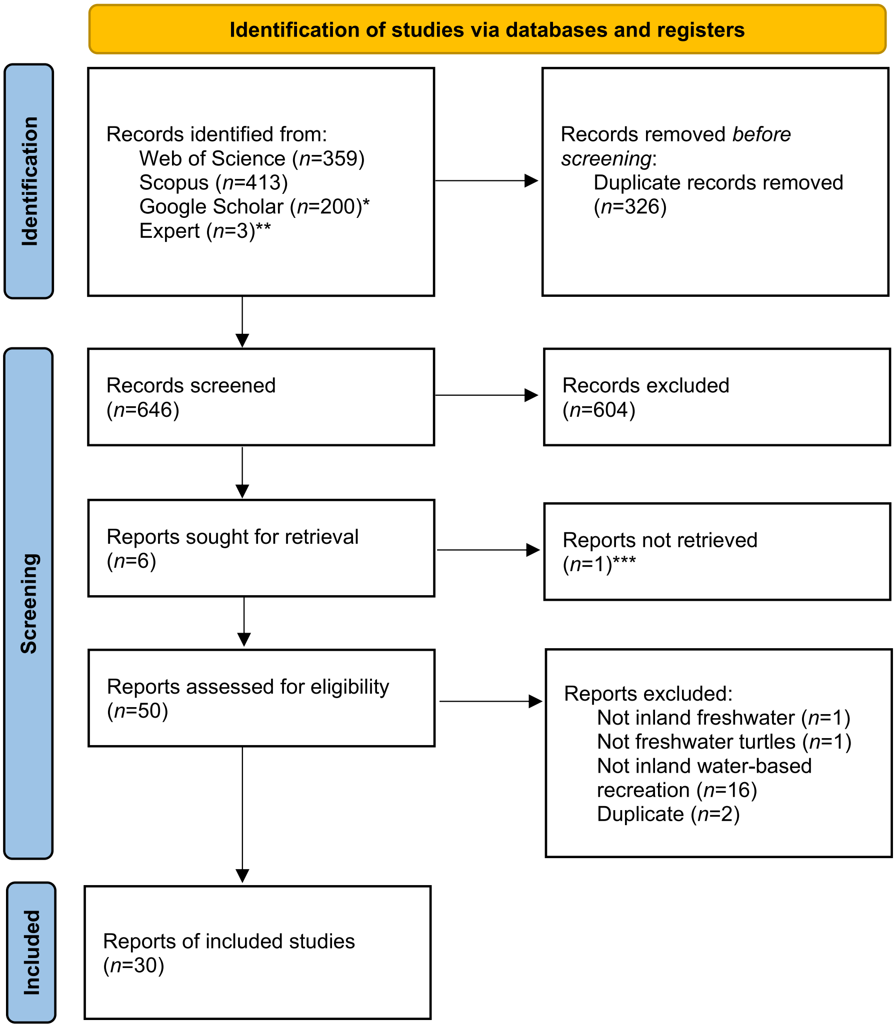

FIGURE 1 Flow diagram adapted from Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRIMSA) (Page et al., 2021) illustrating sources searched and screened for the review. *Only the first 200 out of 2560 search results were collected from Google Scholar. **Relevant articles identified by an expert which were included in the review. ***Articles unable to be retrieved after searching with Carleton University subscription, inter-library loan services, ResearchGate, Google and by contacting the author(s).

the 20 freshwater turtle species studied in the included articles, 11 are listed as Least Concern, one as Near Threatened, three as Vulnerable, two as Endangered and one as Data Deficient (Table 1). However, these turtle species were last assessed between 1996 and 2011, with the majority assessed in 2010 ($n = 14$, 74%).

Seven types of turtle data collection methods were identified across articles: capture survey, visual survey, temperature, X-ray, blood sample, radio telemetry and laboratory trials (Figure 2). Capture survey ($n = 24$ articles) was defined as capturing or trapping turtles using methods such as basking traps, fyke nets and snorkeling with dip nets (e.g. Bennett et al., 2009). Turtle capture surveys also typically involved marking turtles and recording any physical abnormalities or injuries. Turtle visual surveys ($n = 11$ articles) included photo evidence of turtles (e.g. Browne et al., 2020) or on-site observations of turtles (e.g. Bulté et al., 2009). Temperature ($n = 6$ articles) included recording turtle temperature (e.g. Thermochron iButtons; Heppard & Buchholz, 2019) and/or ambient temperature (e.g. on-site weather station data; Bulté et al., 2009) to understand turtle thermoregulatory behaviours. X-rays ($n = 6$ articles) involved radiograph scans of internal turtle structure (e.g. X-raying for ingested fishing hooks; Steen et al., 2014). Blood samples ($n = 2$ articles) were taken from turtles as an index for stress (e.g. blood samples to measure cortisol levels in turtles; Polich, 2016). Radio telemetry ($n = 2$ articles) was used to record turtle movement data (e.g. Laverty et al., 2016). Laboratory trials ($n = 2$ articles) involved recording data on wild turtles via experimental trials in an indoor and/or outdoor apparatus (e.g. Jain-Schlaepfer et al., 2017).

Five types of human data collection methods were identified across articles: interviews, recreation database, recreation visual survey, participatory science (a.k.a. community science or citizen science) and site assessment (Figure 2). Opportunistic discussions ($n = 5$ articles) involved researchers speaking with water-based recreation users and riverine landowners about their experiences and observations (e.g. Browne et al., 2020). Recreation visual surveys ($n = 7$ articles) involved researchers observing water-based recreational activities such as number of fishers (Pittfield & Burger, 2017), number of bush hooks (e.g. Enge et al., 2014) or observing boat traffic and the effects boat presence had on turtles (e.g. Heppard & Buchholz, 2019). Recreation databases ($n = 5$ articles) involved using previously collected data on recreation use, such as campsite usage (Laverty et al., 2016), recreation permits (Heppard & Buchholz, 2019), records of boat vessel crossing data (Turcotte

TABLE 1 List of freshwater turtle species included in the article search and their designations in the International Union for Conservation of Nature (IUCN) Red List.

Scientific name	Common name	No. of articles	IUCN Red List
Apalone mutica	Smooth softshell turtle	1	LC (2010)
Apalone spinifera	Spiny softshell turtle	5	LC (2010)
Chelydra serpentina	Snapping turtle	7	LC (2010)
Chrysemys picta	Painted turtle	10	LC (2010)
Emys trinacris	Sicilian pond turtle	1	DD (2004)
Glyptemys insculpta	Wood turtle	2	EN (2010)
Graptemys flavimaculata	Yellow-blotched map turtle	2	VU (2010)
Graptemys geographica	Northern map turtle	7	LC (2010)
Graptemys oculifera	Ringed map turtle	1	VU (2010)
Graptemys ouachitensis	Ouachita map turtle	1	LC (2010)
Graptemys pseudogeographica	False map turtle	1	LC (2010)
Kinosternon subrubrum	Eastern mud turtle	1	LC (2011)
Macrochelys suwanniensis	Suwannee snapping turtle	1	N/A[a]
Macrochelys temminckii	Alligator snapping turtle	3	VU (1996)
Pseudemys alabamensis	Alabama red-bellied cooter	1	EN (1996)
Pseudemys concinna	River cooter	1	LC (2010)
Pseudemys gorzugi	Rio Grande cooter	2	NT (2010)
Pseudemys rubriventris	Northern red-bellied cooter	1	NT (2010)
Sternotherus odoratus	Common musk turtle	5	LC (2010)
Trachemys scripta	Pond slider	10[b]	LC (2010)

Note: Since the last assessments of these freshwater turtles, major threats such have habitat loss, collection for the pet trade and human consumption continue and in some cases have increased (Stanford et al., 2020). Therefore, it is possible that these freshwater turtle species face greater threats now than they did at the time of their last assessments.

IUCN abbreviations: DD, data deficient; EN, endangered; LC, least concern; NT, near threatened; VU, vulnerable.

[a]*M. suwanniensis* was discovered as a genetically and morphologically distinct species from *M. temminkii* in 2014 and has not yet been assessed by the IUCN (Enge et al., 2014).

[b]This count includes *Trachemys scripta elegans* (red-eared sliders; $n = 5$ articles).

et al., 2023) or boat registration data (Selman et al., 2013; Vecchioni et al., 2020). Participatory science ($n = 2$ articles) included gathering data submitted by water-based recreation users either by online forum (Browne et al., 2020) or social media (Vecchioni et al., 2020). Site assessment ($n = 1$ articles) looked at environmental changes caused by human impact (Laverty et al., 2016).

Although all articles included focused on human–turtle interactions during water-based recreation, turtle data were collected more often than human data to analyse these interactions (Figure 3). Fourteen of the 30 included articles solely collected turtle data to study human–turtle interactions (e.g. Bennett et al., 2009; Leary et al., 2008). Interestingly, there were no articles that solely collected human data to study human–turtle interactions. Instead, whenever human data were collected, they were in tandem with turtle data. For example, both turtle and human recreation visual surveys were used to study boat traffic impacts on turtle basking behaviour (e.g. Heppard & Buchholz, 2019; Pittfield & Burger, 2017; Selman et al., 2013). Also, when studying angler interactions with turtles, many articles focused on collecting turtle disturbance data (via capture survey, visual survey or X-rays) and complemented it with human data collection (via opportunistic discussions with recreational fishers and riverine landowners on their observations and experiences interacting with turtles) (Browne et al., 2020; Galois & Ouellet, 2007; Leary et al., 2008; Steen et al., 2014; Steen & Robinson, 2017).

4 | SYNTHESIS

Twenty-nine of the 30 articles reported adverse effects following interactions between humans and freshwater turtles during water-based recreation. These negative effects were further categorized as water-based recreational activities that directly or indirectly affected freshwater turtles. Three articles reported interactions as having no effect, meaning turtles were not affected by water-based recreation, or the interaction could be framed as either having a negative or positive effect on turtles. Although one article reported positive interactions between turtles and inland water-based recreation, 11 articles suggested potential human water-based recreation conservation measures that can mitigate risk from recreational activities to turtle populations.

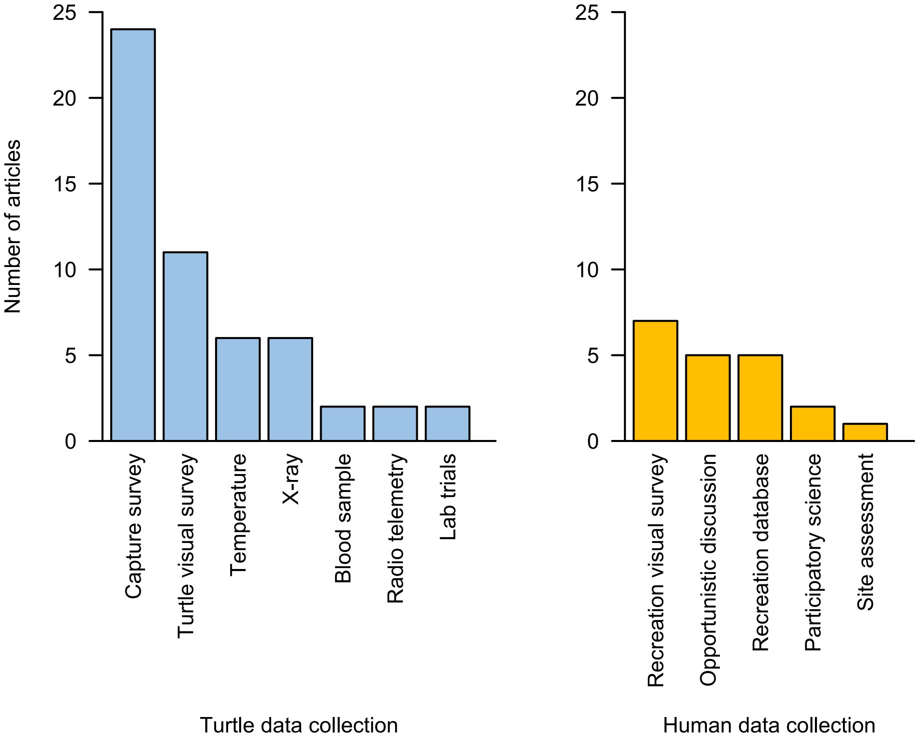

FIGURE 2 Turtle and human data collection methods used across included articles ($n = 30$).

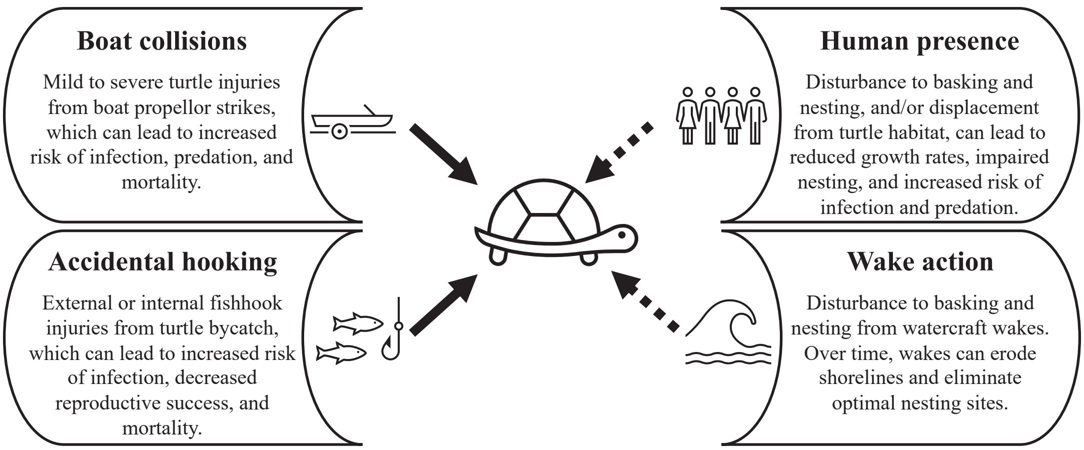

FIGURE 3 Negative human–turtle interactions during inland water-based recreation. Solid arrows indicate that the interaction has direct impacts on freshwater turtles; dashed arrows indicate that the interaction has indirect impacts on freshwater turtles.

4.1 | Negative interactions

The following sections identify the direct and indirect negative interactions between humans and freshwater turtles during inland water-based recreation (Figure 3 and Table 2), specifically how recreation leads to negative effects on turtles and the long-term implications of these effects at the individual and/or population level. The sections are framed to give an overview of negative impacts of water-based recreation to freshwater turtles and identify articles that may provide further in-depth analysis on changes to turtle behaviour and physiology.

4.1.1 | Negative, direct effects: Boat collisions

Recreational boating involves operating high-powered watercraft (e.g. powerboats and jetskies) in aquatic environments. Nine articles reported negative, direct interactions between inland water-based recreational boating and turtles (Table 2). Article publication year ranged from 2006 to 2018 and were located in two countries (Canada, USA). In total, 13 freshwater turtle species were studied (Table 2).

Negative, direct interactions between recreational boats and turtles are caused by collision with boat propellers. As boats move in water, their propellers can collide with turtles swimming or aquatic

TABLE 2 Articles reporting negative human–turtle interactions during inland water-based recreation.

Human–turtle interaction	Turtle species studied	References
Boat collisions	*A. mutica*, *A. spinifera*, *C. picta*, *C. serpentina*, *G. geographica*, *G. ouachitensis*, *G. pseudogeographica*, *G. flavimaculata*, *M. temminckii*, *P. alabamensis*, *P. concinna*, *S. odoratus*, *T. scripta*.	Smith et al. (2006); Galois & Ouellet (2007); Leary et al. (2008); Bulté et al. (2009); Spencer & Janzen (2010)[a]; Selman et al. (2013); Bennett & Litzgus (2014); Hollender et al. (2018); Smith et al. (2018).
Accidental hooking	*A. spinifera*, *C. picta*, *C. serpentina*, *E. trinacris*, *G. insculpta*, *M. suwanniensis*, *M. temminckii*, *P. alabamensis*, *P. gorzugi*, *S. odoratus*, *T. scripta*.	Galois & Ouellet (2007); Leary et al. (2008); Spencer & Janzen (2010); Enge et al. (2014); Steen et al. (2014); Mays et al. (2015); Steen & Robinson (2017); Waldon et al. (2017); Suriyamongkol et al. (2019); Browne et al. (2020); Mahan et al. (2020); Vecchioni et al. (2020); Mahan et al. (2022).
Human presence near habitats used by turtles	*C. picta*, *G. flavimaculata*, *G. geographica*, *G. insculpta*, *G. oculifera*, *K. subrubrum*, *P. rubriventris*, *S. odoratus*, *T. scripta*.	Garber & Burger (1995); Moore & Seigel (2006); Bulté et al. (2009); Spencer & Janzen (2010); Selman et al. (2013); Laverty et al. (2016); Polich (2016); Pittfield & Burger (2017); Jain-Schlaepfer et al. (2017); Heppard & Buchholz (2019); Bulté et al. (2020); Turcotte et al. (2023).
Wake action and shoreline erosion on habitat used by turtles	*C. picta*, *G. flavimaculata*.	Moore & Seigel (2006); Spencer & Janzen (2010); Selman et al. (2013).

[a]Spencer & Janzen (2010) modelled overall water-based recreation impacts on turtle life history traits; thus, this article can be applicable to all types of human–turtle interactions listed above.

basking, resulting in mild to severe turtle injuries. Mild turtle injuries from boat collisions can include shell scars (Bulté et al., 2009; Galois & Ouellet, 2007; Hollender et al., 2018). Over time, shell injuries can lead to deformities (Bennett & Litzgus, 2014). Severe propeller injuries include deep wounds exposing soft tissue under shells (Leary et al., 2008), as well as the laceration or amputation of limbs (Hollender et al., 2018), which may result in deformities that can affect locomotion (Bennett & Litzgus, 2014). Moreover, severe turtle injuries from boat collisions can result in traumatic head injuries, which can cause brain damage or blindness (Galois & Ouellet, 2007). Boat collisions can also cause direct mortality, but it is difficult to quantify this because it is rare to recover turtle carcasses quickly enough in the wild to determine that the cause of death was from boat collision (Bulté et al., 2009; Selman et al., 2013). As a result, boat collision mortality rate for turtles in the literature may be underestimated.

Freshwater turtles injured from boat collisions may be susceptible to delayed consequences, such as an increased risk of infection, increased risk of predation and mortality. Turtles with boat collision injuries that leave open skin wounds may be more prone to pathogens (Galois & Ouellet, 2007). Moreover, turtles with boat collision injuries can develop visual and/or mobile disabilities, impairing their predator detection and predator escape responses (Bennett & Litzgus, 2014; Galois & Ouellet, 2007). Thus, increased susceptibility to infection and/or depredation could have negatively impacts later on survival rates of turtles that survive boat collisions.

The risk of turtle injury from boat collisions can vary within and between species. For instance, turtles with larger body sizes may have a higher likelihood of colliding with boat propellers (Bennett & Litzgus, 2014; Bulté et al., 2009; Galois & Ouellet, 2007). Within species, many freshwater turtles exhibit sexual size dimorphism, presumably making the larger sex more susceptible to boat collisions than smaller sized adults of the opposite sex and juveniles. For example, adult females of northern map turtle (*G. geographica*) are more than twice the size of adult males and are two to nine times more likely to have propeller injuries than adult males (Bulté et al., 2009). This could also be because adult females use open-water habitats more frequently than smaller adult males and juveniles (Carrière & Blouin-Demers, 2010). In addition, small adult males are likely to be obliterated by a boat strike, thus will not survive to show injuries as adult females do (Bulté et al., 2009). The risk of injury from boat collisions may also vary with turtle habitat use. Turtle species that prefer benthic and shallow-water habitats are less likely to be injured by boat collisions than species that prefer open-water habitats (Hollender et al., 2018; Smith et al., 2018). For example, the less reported incidence of boat propeller injuries in snapping turtles (*C. serpentina*) may reflect their greater use of benthic habitats, whereas greater reported incidence of boat propeller injuries in more pelagic species such as painted turtles suggests they are more likely to encounter boats (Smith et al., 2018). Turtle behaviours may also influence the likelihood of colliding with a boat. For example, turtles choosing to bask in thick algal mats may be at a higher risk of boat collision, as the vegetation around them can make it more challenging to dive beneath the surface and away from boats (Bulté et al., 2009). Increased movements such as the yearly migrations female turtles make to nesting sites may also increase the risk of boat encounters and collisions (Bennett & Litzgus, 2014; Bulté et al., 2009).

The risk of turtle injury from boat collisions also varies with boat traffic. For example, Bulté et al. (2009) compared boat collision injuries of northern map turtles between low and high boat traffic water bodies in Canada (Lake Opinicon and the St. Lawrence River, respectively). The rate of boat collision injury for northern map turtles in Lake Opinicon was 3.8%, but the rate of injury in the St. Lawrence River was 8.3% (Bulté et al., 2009). The popularity of recreational boating has increased over the years, which may increase the risk of turtles being injured by boat collisions (Smith et al., 2006). A 35-year study (1979–2014) monitoring a turtle community in Dewart Lake, Indiana, USA found that boat propeller impacts on turtles have steadily increased over time, with reduced injury rates during economic downturns and recessions (i.e. hiked gas prices and reduced visitation to parks) (Smith et al., 2018).

4.1.2 | Negative, direct effects: Accidental hooking

Accidental hooking occurs when recreational fishers hook non-targeted species (i.e. bycatch). Thirteen articles reported negative, direct effect interactions between freshwater-based recreational fishers and accidentally hooked turtles (Table 2). Article publication year ranged between 2007 and 2022 and were located in three countries (Canada, Italy, USA). In total, 11 freshwater turtle species were studied (Table 2).

Accidental hooking of turtles during recreational fishing can lead to external and/or internal injuries. Hooks caught externally on a turtle's mouth may impede turtle feeding (Galois & Ouellet, 2007). If swallowed, hooks can lead to internal injuries such as scraping the inside of the gastrointestinal tract (Borkowski, 1997). In south-eastern USA, X-rays have found J hooks, circle hooks and treble hooks in turtles, and in some cases, a combination of hooks were found in turtles (Steen et al., 2014). Additionally, turtles can be accidentally hooked by trotlines or limblines, fishing lines with hooks that are attached to branches or other shoreline structures and intended for passive fish catch (Enge et al., 2014; Mays et al., 2015). Turtles that swallow fishing hooks with a fishing line trailing behind are associated with the lowest survival rate (Browne et al., 2020; Parga, 2012).

The downstream effects of accidentally hooked freshwater turtles can include increased risk of infection, increased risk of organ damage and turtle mortality. Hooks that leave open wounds externally or cause perforation to internal organs can lead to infection or organ damage (Mahan et al., 2022; Steen et al., 2014). For instance, internally lodged hooks that wound the gastrointestinal tract can lead to cellulitis, peritonitis, stricture formations and organ tearing (Di Bello et al., 2013; Hyland, 2002; Mahan et al., 2022; Valente et al., 2007). Improper hook extraction, such as cutting the fishing line when a turtle is caught, further increases the risk of negative effects on turtles as the hook is left on or in the turtle (Leary et al., 2008). Moreover, if hooks ingested with fishing lines have lead sinkers, it may induce lead poisoning, consequently increasing the risk of general muscle weakness or depression in turtles (Borkowski, 1997). Severe infections or lethal punctures to gastrointestinal organs (e.g. punctures to stomach lining) can cause turtle mortality (Steen et al., 2014). Mortality rates of accidentally hooked freshwater turtles are unknown as existing data are from wild-caught turtles that survived being hooked (Steen & Robinson, 2017) or from a few opportunistic and inconclusive observations (Vecchioni et al., 2020). However, population modelling (using observed ingested hooking and sea turtle ingested hooking mortality data) on snapping turtles, pond sliders and alligator snapping turtles (*M. temminckii*) in south-eastern USA has estimated a 1.2–11% probability that an ingested hook will result in mortality, sufficient to cause population declines (Steen & Robinson, 2017).

The prevalence of accidentally hooked turtles from recreational fishing varies within species (sex and age) and between species. Turtles with larger body sizes—either within species (by sex or age) or between species—may have a higher risk of being accidentally hooked, which is attributed to their larger gape size (Steen et al., 2014). However, larger turtles are typically older, and it is also possible that older (larger) turtles simply accumulate more fish hooks over time but are more resistant to surviving being hooked than are smaller, younger turtles (Steen et al., 2014). More research on small turtles is needed to test this hypothesis (Steen et al., 2014). Many freshwater turtle species are opportunistic scavengers and will eat bait used for target fish species; in fact, freshwater turtles are caught using the same bait as fish when targeted by recreational collectors or commercial catch (Mahan et al., 2022; Steen & Robinson, 2017). Therefore, turtle species that prefer the same microsites as targeted fish are more likely to be accidentally hooked by recreational fishers. For example, benthic foragers, such as spiny softshell turtles (*A. spinifera*) and snapping turtles are more likely to be hooked by recreational fishers as popular targeted fish are typically found in the same environments (Galois & Ouellet, 2007; Steen et al., 2014). As another example, a target fish species such as smallmouth bass (*Micropterus dolomieu*) is a warm-water fish that prefers summer temperatures of 30°C, and therefore, turtles with similar preferred or frequented warm temperature microsites in the summer (e.g. common snapping turtle, painted turtle) are more likely to get hooked (Browne et al., 2020). In addition, some turtle diets may preclude accidental hooking compared with others; however, further research is needed to compare turtle diet, habitat use and susceptibility to accidental hooking.

4.1.3 | Negative, indirect effects: Human presence near habitats used by turtles

Human presence near habitats used by turtles may disturb natural turtle behaviours. Twelve articles reported negative, indirect interactions between turtles and inland water-based recreation near habitats used by turtles, including basking sites and nesting sites (Table 2). Article publication year ranged from 1995 to 2023 and were located in two countries (Canada, USA). In total, nine freshwater turtle species were studied (Table 2).

The presence of water-based recreation (e.g., boating and paddling) near freshwater turtle basking sites may disturb turtle basking behaviour. Turtles are ectotherms and need to bask under solar radiation to thermoregulate and perform essential metabolic processes. Turtle basking sites include shorelines, warm waters (i.e. the bottom of shallow waters or the surface of the water) or perches such as driftwood and rocks. Recreational boating passing by turtle basking sites may cause basking turtles to retreat into the water, decreasing the length of time spent basking and thus thermoregulating (Heppard & Buchholz, 2019; Pittfield & Burger, 2017; Selman et al., 2013). For example, in the Pascagoula River, Mississippi, USA, 13% of yellow-blotched map turtles (*G. flavimaculata*) did not return to bask following a boating disturbance, and those that did required 20 min to re-initiate basking, which was more time needed than before the boating disturbance (Moore & Seigel, 2006). Furthermore, recreational fishers in boats that remain near basking sites for prolonged periods of time caused greater disturbances to turtle basking than speed boats, jon boats or personal watercraft passing by the basking site (Moore & Seigel, 2006).

Human disturbances may also affect the spatial ecology and basking perch preference of turtles. Boating presence has been speculated to decrease the occurrence of turtles basking gregariously on perches such as yellow-blotched map turtles (Moore & Seigel, 2006), painted turtles (Pittfield & Burger, 2017) and ringed map turtles (*G. oculifera*) (Heppard & Buchholz, 2019). Gregarious basking increases turtle awareness of predators; if one individual retreats into the water, others basking nearby will soon follow (Shealy, 1976). Slow-moving boats and larger boats near basking sites initiate turtle predator avoidance behaviours of fleeing from basking sites (Heppard & Buchholz, 2019; Selman et al., 2013). Turtles in urban habitats have been reported to bask on perches further away from busy footpaths (Pittfield & Burger, 2017) and tend to avoid exploring other perches because of human presence (Laverty et al., 2016). Although this predator avoidance behaviour may be favourable in terms of avoiding injuries or depredation, it may prevent turtles from finding optimal basking locations and maintaining optimal body temperatures and may decrease reproductive energies (Jain-Schlaepfer et al., 2017).

Similar to basking sites, the presence of water-based recreational activities near freshwater turtle nesting sites may influence turtle nesting behaviour. During the nesting season, gravid (i.e. egg-carrying) female turtles travel from water to land to nest. This travel exposes females to several threats, including predation. The presence of recreational boating disturbances is perceived as a threat by nesting female turtles, making females abandon their nesting attempts; females had less than a 19% chance of completing their oviposition when reaching their nesting site owing to the presence of recreational boats (Moore & Seigel, 2006). In addition, nesting female turtles exposed to high levels of boating disturbances may quicken their nesting times to minimize exposure to disturbances (Moore & Seigel, 2006). Few explanations were proposed for this; either the nest location was predetermined from a previous abandoned attempt, or nesting speed was selected to avoid disturbances (Moore & Seigel, 2006).

Human presence near turtle basking and nesting sites may have long-term consequences at the individual and population levels. In general, turtles exposed to high levels of boat activity exhibit more risk-prone, defensive behaviour, demonstrating a low tolerance for frequent human disturbances (Turcotte et al., 2023). Disruption to turtle basking behaviour by recreational boating impairs turtle thermoregulation required to maintain optimal body temperatures (Jain-Schlaepfer et al., 2017), and disturbed turtles take a longer time to resume basking (Bulté et al., 2020). Reduced thermoregulation in turtles may lead to lower food processing rates and therefore lower energy assimilation rates, which may result in an increased susceptibility to environmental parasites and predation (Moore & Seigel, 2006). Furthermore, decreased basking opportunities in the spring, and thus decreased metabolic thermoregulation in the spring, can impede egg and sperm production for adult turtles and impede growth in juvenile turtles (Jain-Schlaepfer et al., 2017). Turtles at disturbed basking sites may also have higher stress levels and poorer shell conditions compared with turtles at undisturbed basking sites (Selman et al., 2013).

The degree of recreational activities disturbing turtles at basking and nesting sites depends on boat traffic (Heppard & Buchholz, 2019; Moore & Seigel, 2006; Pittfield & Burger, 2017; Selman et al., 2013). Recreational boat traffic varies throughout the week, with higher boat traffic on weekends than weekdays (Moore & Seigel, 2006). In one study, it was found that turtles were 22 times more likely to be disturbed by boat traffic in rivers popular for boating activity at a weekend and five times more likely on a weekday (Selman et al., 2013). In addition, boating activity tends to differ based on the time of day, increasing at around 12:30 h (Moore & Seigel, 2006). Coincidentally, basking occurrence was found to decrease for female turtles around the same time of day; however, whether this was caused by increased boat traffic or turtles halting basking to cool off during the warmer time of day was inconclusive (Moore & Seigel, 2006). Moreover, nesting females tend to travel more in June and July in search of nesting sites, which coincides with an increase in boating traffic compared with other months of the year (Bulté et al., 2009).

4.1.4 | Negative, indirect effects: Wake action and shoreline erosion on habitat used by turtles

The generation of wakes from watercraft, and the gradual shoreline erosion from continuous wake action, can disrupt aquatic species and their habitats. Three articles reported negative, indirect effect interactions between turtles, wake action and shoreline erosion from inland water-based recreation (Table 2). Article publication year ranged between 2006 and 2013 and were located in one country (USA). Two freshwater turtle species were studied (Table 2).

Boat speeds and size influence wake action, which can affect turtle behaviours. Slower, larger boats cause more disturbances than faster, smaller boats as they remain within the vicinity of basking turtles for a longer time, and can cause larger wakes, pushing turtles off basking perches in the water even if they are not disturbed by their presence (Selman et al., 2013). Boats travelling at faster speeds generally speed by turtle habitats, causing relatively minimal disturbance by only being present for a short time. The exception to this observation is when multiple passing personal watercrafts generate large, compounded wakes, which can disturb basking turtles or completely submerge basking structures (Heppard & Buchholz, 2019). Large-sized boats may create larger wakes than medium and small-sized boats, consequently being more disruptive to turtles (Selman et al., 2013).

An increase in boating traffic in freshwater systems over the years, and thus an increase in wake action, has resulted in shoreline and sandbar erosion, damaging or destroying potential turtle nesting habitat (Heppard & Buchholz, 2019; Selman et al., 2013). Continuing wake action can cause vertical shelves on shores and sandbars, preventing females from accessing optimal nesting sites (Selman et al., 2013). When nesting habitat is destroyed by wake action and shoreline erosion, nesting female turtles may travel further in water or on land to reach nesting sites, increasing their risk of collisions with boats and cars (Bulté et al., 2009).

4.2 | No-effect interactions

Three articles with publications years ranging from 2008 to 2016 and located across two countries (Canada, USA) reported no-effect interactions between inland water-based recreation and turtles (Bowen & Janzen, 2008; Laverty et al., 2016; Polich & Barazowski, 2016). Two freshwater turtle species were studied (*C. picta*, *S. odoratus*).

Common musk turtles (*S. odoratus*) at high traffic recreation sites were not found to have significant injuries and showed no difference in home range sizes and daily movement patterns (i.e. were not disturbed) compared with low recreation sites (Laverty et al., 2016). However, with support from arguments earlier in this article, this no-effect interaction of common musk turtles could be the result of their small body size and being bottom-dwellers naturally decreasing their exposure to water-based recreation (Bennett & Litzgus, 2014; Bulté et al., 2009; Galois & Ouellet, 2007; Hollender et al., 2018; Smith et al., 2006). In other examples, the intensity of human presence had no effect on painted turtle basking behaviours or on nesting habitat selection (Bowen & Janzen, 2008; Polich & Barazowski, 2016). Turtle habituation to human presence may be because turtles are long-lived animals and over time have less behavioural response to supposedly non-threatening human approaches (Polich & Barazowski, 2016; Selman et al., 2013). However, desensitization to human approaches may increase susceptibility of negative water-based recreation impacts when turtles are in danger (Lester et al., 2013). Ultimately, the impact of water-based recreation on freshwater turtles can be species-specific (depending on turtle morphology and behaviour) and site-specific (depending on the water body and recreation type and intensity).

4.3 | Positive effect interactions

Only one article, located in the USA, reported positive human–turtle interactions during inland water-based recreation considering four freshwater turtle species (*A. spinifera*, *C. picta*, *C. serpentina*, *G. geographica*) (Lindeman, 2020). This article found that turtle watching enhanced water user experiences, with a locally funded turtle observation deck becoming a popular attraction site for visitors (Lindeman, 2020). Visitor perception of turtles was highly positive and created a culture of visitors becoming more inclined to boat a further distance from basking turtles to avoid potentially disturbing them (Lindeman, 2020). In addition, there was a case of speculation about a positive interaction in which turtles could indirectly benefit from eutrophication from outboard motor pollution (Laverty et al., 2016). Turtle benefits from eutrophication could include more food and cover from increased vegetation, especially around popular areas such as campsites (Laverty et al., 2016). However, eutrophication can come from a myriad chemical impacts (e.g. agricultural fertilizers and high sewage levels). Therefore, positive effects of interactions between turtles and water-based recreation need further research.

4.4 | Conservation measures

Eleven articles mentioned risk mitigation and conservation measures that can be implemented during inland water-based recreation (Table 3). However, risk mitigation and conservation measures were recommended based on article findings, rather than tested and measured for efficacy. The articles spanned three countries (Canada, Italy, USA) and were published between 2006 and 2020, and studied 16 freshwater turtle species (Table 3).

The risk of water-based recreational activities on turtles can be mitigated by regulating boat speeds and boat access near habitats used by turtles (Bulté et al., 2009; Hollender et al., 2018). Regulating boat speeds and limiting large boats near habitats used by turtles minimize the number of disturbances and injuries observed in turtles (Galois & Ouellet, 2007; Hollender et al., 2018; Selman et al., 2013). In addition, implementing 'no wake' zones near basking sites reduces the size of wakes near sites and reduces the amount of shoreline erosion that adversely affects the quality and accessibility of nesting sites (Heppard & Buchholz, 2019). However, it can also make boats slower, which can disturb more turtles (Selman et al., 2013). Regulating boat access to certain areas of the water enables turtles to have enough basking or nesting time before encountering a disturbance. For example, preventing large boats from gaining access to smaller rivers can reduce turtle disturbances (Selman et al., 2013). Other studies have suggested developing protection areas or sanctuaries to limit boat access in habitats used by turtles (Galois & Ouellet, 2007; Hollender et al., 2018). At least limiting boat access to certain areas during specific times of the year or day(s) of the week may result in a less invasive regulation to boaters while still providing breaks from disturbances to the turtles; however, further research is needed on this (Heppard & Buchholz, 2019; Moore & Seigel, 2006). Restricting fishing permits may decrease the presence of fishing boats near habitats used by turtles, such as basking sites, where stalled fishing boats cause high levels of disturbances to basking turtles (Moore & Seigel, 2006).

Another conservation measure to mitigate turtle risk during inland water-based recreation is to install more basking perches. Installing basking perches may lead to more availability of undisturbed basking sites for turtles in their habitats (Heppard & Buchholz, 2019; Pittfield & Burger, 2017), especially in open waters such as lakes, that have fewer snag habitats.

TABLE 3 Conservation measures discussed for interactions between freshwater turtles and water-based recreational activities.

Conservation measures	Turtle species studied	References
Regulating boat speeds, size and access points	*A. mutica*, *A. spinifera*, *C. serpentina*, *G. flavimaculata*, *G. geographica*, *G. oculifera*, *G. ouachitensis*, *G. pseudogeographica*, *M. temminckii*, *P. concinna*, *S. odoratus*, *T. scripta*.	Moore & Seigel (2006); Galois & Ouellet (2007); Bulté et al. (2009); Selman et al. (2013); Bennett & Litzgus (2014); Jain-Schlaepfer et al. (2017); Hollender et al. (2018); Heppard & Buchholz (2019).
Protection of habitats used by turtles	*A. mutica*, *A. spinifera*, *C. serpentina*, *G. flavimaculata*, *G. oculifera*, *G. ouachitensis*, *G. pseudogeographica*, *M. temminckii*, *P. concinna*, *S. odoratus*, *T. scripta*.	Moore & Seigel (2006); Galois & Ouellet (2007); Hollender et al. (2018); Heppard & Buchholz (2019).
Designating 'no wake' boating zones	*G. oculifera*.	Heppard & Buchholz (2019).
Restricting fishing permits	*G. flavimaculata*.	Moore & Seigel (2006).
Installing turtle basking perches	*C. picta*, *G. oculifera*, *K. subrubrum*, *P. rubriventris*, *S. odoratus*, *T. scripta*.	Pittfield & Burger (2017); Heppard & Buchholz (2019).
Spreading awareness through public education and outreach	*A. spinifera*, *C. picta*, *G. geographica*, *K. subrubrum*, *P. gorzugi*, *P. rubriventris*, *S. odoratus*, *T. scripta*.	Galois & Ouellet (2007); Jain-Schlaepfer et al. (2017); Pittfield & Burger (2017); Suriyamongkol et al. (2019).
Participatory science and stewardship programmes	*C. picta*, *E. trinacris*, *G. geographica*, *K. subrubrum*, *P. rubriventris*, *S. odoratus*, *T. scripta*.	Galois & Ouellet (2007); Pittfield & Burger (2017); Vecchioni et al. (2020).

Spreading awareness of water-based recreation impacts on turtles informs water users about how to mitigate risks to turtles (Browne et al., 2020; Galois & Ouellet, 2007; Jain-Schlaepfer et al., 2017; Pittfield & Burger, 2017). Spreading awareness can include informing recreational fishers at fishing stores or social media on how to safely unhook a turtle (Browne et al., 2020; Galois & Ouellet, 2007), promoting unleaded fishing sinkers to prevent turtles accidentally swallowing harmful lead products (Galois & Ouellet, 2007) and placing signage at recreational park entry points to encourage pro-environmental and -conservation behaviours (Pittfield & Burger, 2017). In addition, community engagement through participatory science and stewardship programmes increases awareness and reinforces pro-environmental behaviours for water users to mitigate risk to turtles (Galois & Ouellet, 2007; Pittfield & Burger, 2017; Vecchioni et al., 2020). For example, in Lake Champlain, Québec, a participatory science network for spiny softshell turtles was created to collect turtle monitoring data and inform the community about water-based recreation conservation measures for this species (Galois & Ouellet, 2007). However, to spread awareness successfully on turtle conservation measures or to promote turtle conservation opportunities for public involvement, it is important to understand water users' underlying environmental consciousness that can influence their willingness to absorb new information and adopt conservation behaviours (Vecchioni et al., 2020).

5 | FUTURE RESEARCH

In this review, only 30 articles were identified, indicating further research is needed to understand human–turtle interactions during inland water-based recreation. Twenty-eight articles were in peer-reviewed academic literature, highlighting the lack of other types of articles (e.g. grey literature) in the field. Future reviews in this field could search beyond Web of Science, Scopus and Google Scholar databases used in this review for a greater scope in search results. For example, searches on government websites, NGO websites or other search engines may highlight more grey literature missed in this review's search approach. There was a geographic bias, with 29 of the 30 articles based in North America. This may partly reflect searches being restricted to English language only. Future reviews are encouraged to capture a greater diversity of languages.

Future research should also explore other types of inland water-based recreation and habitat alterations associated with recreation. Most articles in this review focused on only two types of inland water-based recreation: boating and fishing. Additional research in this field should explore the human–turtle interactions of other water-based recreational activities. These include canoeing, waterskiing or swimming and interactions found in other types of water bodies—for example, turtles in brackish water habituated to boat noise (Lester et al., 2013). Future research might also investigate turtle-specific impacts from recreation-driven habitat alterations, such as the effect of macrophyte removal for boat access on turtle habitat availability, or the effects that ice removal equipment like bubblers have on turtle predation during overwintering. In addition, future research is needed on recreational boat traffic in fresh waters influencing turtle communication, a finding already detected with recreational boats and marine wildlife (e.g. Jensen et al., 2009; Pine et al., 2021).

Although interactions between humans and freshwater turtles during water-based recreation involve both human and ecological dimensions, this review found that turtle data were used more than human data to study these interactions (Figure 2). Additional human dimension research that explores perspectives and knowledge from water users, land managers, policymakers and other freshwater turtle experts may provide insight on the nuances of human–turtle interactions during water-based recreation and may altogether uncover new interactions. Positive interactions for turtle risk mitigation were based on author discussion and speculation from article findings. Collaboration between researchers and water users can lead to conservation innovations, such as developing fishing technology that can mitigate the risk of accidentally hooking freshwater turtles (Steen & Robinson, 2017). Additional research on human–turtle interaction during water-based recreation can focus on the efficacy of freshwater turtle risk mitigation and conservation measures during recreation, both in terms of appropriate measures that have positive impacts on turtle populations and feasible measures that water users will likely uptake (Pittfield & Burger, 2017; Steen & Robinson, 2017).

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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