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A standardized drone-based protocol for monitoring freshwater turtles

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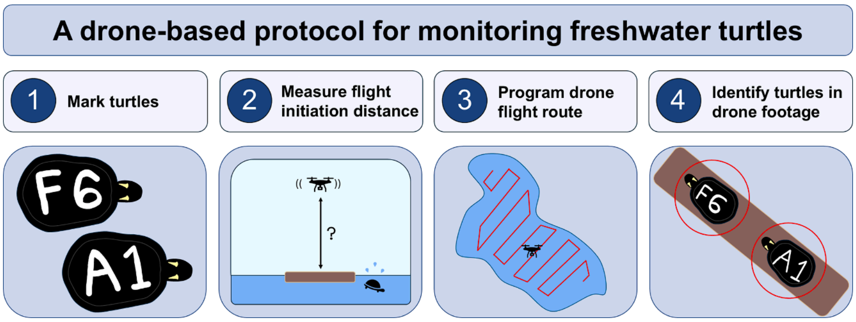
GRAPHICAL ABSTRACT



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ABSTRACT

Basking is an essential thermoregulatory behaviour for freshwater turtles, but accurately estimating basking duration is challenging due to the limitations of traditional survey methods. Traditional methods afford lower detection probabilities, are often disruptive, and lack precision due to infrequent sampling. To address these limitations, we developed a high-frequency drone-based monitoring method that records repeated, minimally invasive video surveys of individually marked painted turtles (*Chrysemys picta*). The method involves three main elements:

- Programming an autonomous drone route at fixed, short intervals covering the entire study area
- Recording drone videos to document turtles basking without altering their behaviour
- Manually reviewing video footage to quantify basking occurrence and duration

We implemented this method at a wetland on the Kenauk property in Montebello, Québec, Canada. We monitored 62 painted turtles from June to September 2025. A DJI Mini 4 Pro drone

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performed an autonomous survey of the wetland every 20 min, producing 423 surveys and 127 h of video over 13 days. Flight initiation distance trials confirmed that surveys conducted at an altitude of 15 m did not initiate escape responses in painted turtles. Drone surveys allow for quantification of individual basking behaviour with unprecedented frequency and without being invasive.

Specifications table

Subject area	Agricultural and Biological Sciences
More specific subject area	Wildlife drone surveys
Name of your method	Monitoring freshwater turtles with drones
Name and reference of original method	
Resource availability	DJI Mini 4 Pro: https://www.dji.com/ca/mini-4-pro WaypointMap software: https://www.waypointmap.com/

Background

Basking is an essential thermoregulatory behaviour in most reptiles, including freshwater turtles, that facilitates physiological processes and, hence, affects fitness [1–3]. Accurately estimating basking duration in freshwater turtles, however, is challenging. Traditional methods used to quantify basking duration include shore-based or canoe surveys, but both methods have shortcomings. For example, in shore-based observations, turtles can be obstructed by habitat features like emergent vegetation [4,5], and canoe surveys can disturb turtles, thus artificially shortening basking duration [6]. Wildlife cameras, on the other hand, require prior identification of basking sites for proper camera placement and have a restricted field of view, allowing some turtles to avoid detection. Basking duration estimates using traditional observation methods could also be less precise due to the surveillance process taking longer and, therefore, occurring relatively infrequently (e.g., every hour; [7,8]).

Uncrewed Aerial Vehicles (UAVs), or drones, are increasingly used in ecological research, providing a safe, efficient, and minimally disruptive method for monitoring wildlife [9–11]. Despite their growing use in wildlife research, drone-based methods for studying freshwater turtles remain limited and have not yet been used to identify individual turtles reliably or to quantify basking behaviour [4, 5,12–14]. This methodological gap restricts the ability to study basking behaviour from an aerial perspective and at high temporal frequencies. To address these limitations, we developed a drone-based method for repeatedly surveying freshwater turtles at a high temporal frequency to obtain individual-level records of basking occurrence and duration.

Method details

Project overview

Fieldwork took place at a wetland on the Kenauk property in Montebello, Québec, Canada (Fig. 1). We trapped 62 painted turtles with hoop nets and marked them with unique alphanumeric codes painted on their carapace (Fig. 2). After the turtles were marked, we performed drone surveys to monitor their basking behaviour from early June until late September 2025 (13 days). We programmed an autonomous route on the DJI Mini 4 Pro to run every 20 min throughout the day, capturing nadir-oriented RGB video used to detect

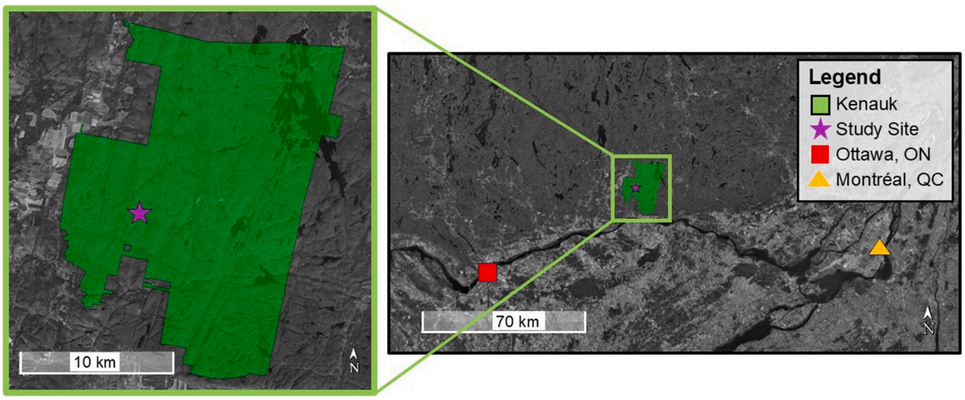

Fig. 1. Kenauk property in Montebello, Québec, Canada, where the basking behaviour of painted turtles was studied in 2025.

and identify individual turtles in the wetland. Each survey generated continuous video footage that was later reviewed to determine which individuals were basking when, which allowed us to calculate basking duration. The methodological details presented here follow a standardized reporting protocol for drone-based wildlife research [15].

Drone system and operation details

Platform specifications

We used two identical DJI Mini 4 Pro drones (Fig. 3), each with its own DJI RC Pro 2 controller. These four-rotor quadcopters were equipped with the DJI Intelligent Flight Battery Plus. Each drone weighed 292 g with the battery installed and measured 148 × 94 × 64 mm when folded without propellers and 298 × 373 × 101 mm when unfolded with propellers. The maximum flight time reported by DJI under controlled conditions is 45 min. In the field with light winds, however, with obstacle avoidance enabled, and landing at ~25 % battery, the maximum safe flight duration was ~30 min. DJI reports a maximum hovering time of 39 min under controlled conditions, but we did not measure this in the field. The drones have a maximum wind resistance of 10 m/s and no rain tolerance.

The Intelligent Flight Battery Plus is a 3850 mAh lithium-ion battery and requires ~78 min to charge fully using a 30 W USB-C charger and DJI Two-Way Charging Hub. A high-capacity charging station powered by a Bluetti AC180P 1440 Wh Portable Power Station supplied three DJI Mini 4 Pro Two-Way Charging Hubs, each capable of charging three batteries simultaneously, for a total of nine batteries (Fig. 4). The station was fully charged before fieldwork and provided sufficient power to maintain a fully charged battery for all the surveys while also powering the two drone remote controllers, a laptop computer, and a smartphone throughout the day.

Takeoff and retrieval

All flights originated from a designated “home base” located ~20 m from the shoreline, approximately equidistant from the start and end points of the autonomous route (see section below). The area was flat and in an opening of the canopy with clear visibility that allowed us to maintain a visual line-of-sight with the drone throughout the flight. We set up a small base area with a shaded workspace and the charging station (Fig. 5). No specialized takeoff equipment was required. To prevent rotor damage from vegetation, we used a plastic storage bin lid as a takeoff and landing platform. After each flight, we returned the drones manually to the home base to land and charge the batteries, and to download video files occasionally from the microSD cards onto a hard drive.

Flight planning and method of operation

We preprogrammed an autonomous flight route using WaypointMap, an online tool for waypoint-based photogrammetry and mapping (Fig. 6). The area of the wetland being surveyed was ~44,345 m^2. We programmed and visualized the autonomous flight on a PC to optimize wetland coverage and minimize survey duration. The .KMZ file generated by WaypointMap was installed on the DJI RC Pro 2 controllers via a placeholder route created in DJI Fly. At the field site, we tested the programmed route and made minor adjustments to avoid the drone approaching trees too closely. This required several rounds of iterative testing: running the route on site, returning to a location with internet access to modify the route on a PC, downloading the updated file onto the controller, and retesting in the field. We also tried using DJI Fly for flight programming, but it was unsuitable in this situation because routes could not be edited

Fig. 2. A painted turtle marked with a unique alphanumeric code (F8) painted on its carapace for individual identification via drone footage in a study of basking behaviour at Kenauk, Montebello, Québec, Canada, in 2025.

Fig. 3. DJI Mini 4 Pro drone used to study painted turtle basking behaviour at Kenauk, Montebello, Québec, Canada, in 2025.

on a PC. DJI Fly's requirement to program routes during flight prevented the precise waypoint placement that was needed to cover the entire wetland without gaps or excessive overlap.

We programmed the flight with an altitude of 15 m, the maximum altitude that we found to allow consistent identification of individual turtles from nadir video footage. We set the drone speed to 2.5 m/s and the gimbal angle to –90° for direct overhead imaging. The video started recording at the beginning of the route and stopped at the end of the route. The autonomous flight lasted approximately 18 min. We were typically two people operating the system: the pilot would operate the drone, take off and land the drone, and initiate the autonomous route, and the assistant would manage the charging station and retrieve the drones once they landed.

Payload and data collection

Camera description and data collection methods

We captured all video recordings using the integrated RGB camera of the DJI Mini 4 Pro. The camera has a 1/1.3-inch type CMOS sensor with 48 MP effective pixels and a fixed lens with a field of view of 82.1° and a 24 mm equivalent focal length. The aperture is f/1.7, and the focus range is 1 m to infinity. We recorded video at 4 K resolution (3840 × 2160) at 60 frames per second using H.264/H.265 encoding. We set EV to −3.0, and all other settings (white balance, ISO, shutter speed) were left on auto. We stored videos on microSD cards in the drones (Lexar V30 1066x A2 128 GB and Kingston CanvasGo Plus V30 A2 256 GB). Each sampling day produced approximately 600 GB of video footage. We downloaded video files periodically throughout the day to two redundant external drives: a SanDisk Extreme Portable solid-state drive and a Western Digital My Passport Portable hard-disk drive, ensuring two separate copies of all data to minimize the risk of loss.

Field operation details

We conducted drone surveys on 13 days between 3 June and 26 September 2025. Each sampling day was designed to generate an 18-minute survey every 20 min from 7:20 to 18:40, producing up to 35 surveys per day. Some surveys were unsuccessful due to weather conditions (e.g., heavy wind or rain) or technical issues (e.g., the autonomous route failing to load correctly, obstacle-avoidance halting the mission, or microSD cards reaching capacity). Some surveys were also skipped intentionally later in the season, during the evening when turtles were no longer basking. After accounting for unsuccessful or skipped surveys, we completed 423 surveys across the 13 sampling days, totalling approximately 7614 min (127 h) of usable drone video footage (Table 1).

Two identical DJI Mini 4 Pro drones alternated surveys throughout the day to prevent motor fatigue and overheating, each equipped with its own DJI RC Pro 2 controller. The drone that was not flying and the spare batteries were kept in a shaded area to cool down between flights. Two minutes prior to each survey, we flew the drone manually from the home base to the start point of the autonomous route. We then initiated the autonomous flight through the DJI Fly application on the drone controller, and the drone completed the route. Upon completion, we returned the drone to the home base manually to land it, swap batteries, and recharge. We repeated this procedure for every survey throughout the day. Obstacle avoidance remained enabled for all surveys, and flight altitude

Fig. 4. Charging station used in a study of painted turtle basking behaviour at Kenauk, Montebello, Québec, Canada, in 2025. The charging station consists of a Bluetti Portable Power Station powering three individual DJI Two-Way Charging Hubs with 30 W USB-C chargers, each charging three DJI Intelligent Flight Battery Plus units, for a total of nine batteries.

was consistently 15 m above the ground. Air temperature during surveys ranged from 11 to 31 °C, and wind speeds measured 2 m above the ground ranged from 0 to 1 m/s.

Data analysis

We did not perform post-processing on the raw video data. All analyses were conducted directly from the nadir-oriented RGC videos produced by the DJI Mini 4 Pro. No photogrammetric processing or automated detection algorithms were applied. The video files retained their original spatial resolution throughout analysis, and the spatial resolution of the videos analyzed was identical to that of the raw 4 K imagery originally recorded.

During post-survey analysis, we watched each video at 1x speed and paused whenever a turtle appeared in the frame. This allowed us to zoom in and identify individual turtles based on their unique carapace paint markings (Fig. 7). A turtle was considered to be basking when it was stationary and at least part of its body was out of the water [16,17]. Turtles could sometimes be seen swimming in the drone footage, but only basking turtle observations were recorded.

Permits, regulations, training, and logistics

Drone operations were conducted by a pilot (Lauren Dobie) holding a Small Remotely Piloted Aircraft Basic Operations Certificate issued by Transport Canada (PC2311825878). Research was conducted on the private property of Kenauk with the permission of the Kenauk Institute.

Fig. 5. Home base setup with a workspace and charging station used in a study of painted turtle basking behaviour at Kenauk, Montebello, Québec, Canada, in 2025. The open area where the drone took off and landed, as well as the wetland, are behind the camera.

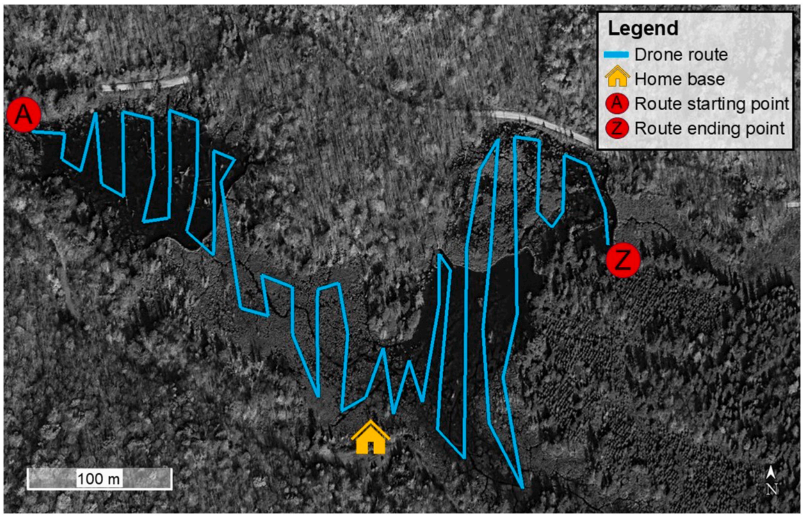

Fig. 6. Autonomous drone route used in a study of painted turtle basking behaviour at Kenauk, Montebello, Québec, Canada, in 2025. The drone took off from the home base, started the route at point A, took a video along the drone route, stopped the route at point Z, and landed back at the home base.

Method validation

Drone disturbance and flight initiation distance

To validate that our drone survey method did not disturb painted turtles or alter their behaviour, we assessed their flight initiation distance (FID). FID is the distance between an approaching threat and an animal at which the animal initiates a behavioural escape response [18–20]. In this case, the drone acted as the perceived threat and the escape response was defined as the turtle leaving the basking site and entering the water. The goal was to identify a survey altitude above the FID to ensure that we did not alter turtle behaviour during the drone surveys.

We conducted FID tests using the DJI Mini 4 Pro, the same platform used for all surveys. We flew the drone above the wetland at an altitude of >20 m until we located a basking turtle. Once a turtle was located, we hovered the drone directly above it at 20 m for 60 s. If

Table 1
Dates of all drone sampling days from a study of painted turtle basking behaviour at Kenauk, Montebello, Québec, Canada. The table includes all sampling days from early June to late September 2025 and the number of completed surveys for each sampling day.

Sampling day	Date	Number of completed surveys
1	3 June 2025	33
2	13 June 2025	35
4	16 June 2025	35
4	25 June 2025	34
5	2 July 2025	27
6	8 July 2025	30
7	22 July 2025	33
8	23 July 2025	34
9	28 July 2025	34
10	21 August 2025	34
11	27 August 2025	34
12	11 September 2025	31
13	26 September 2025	29

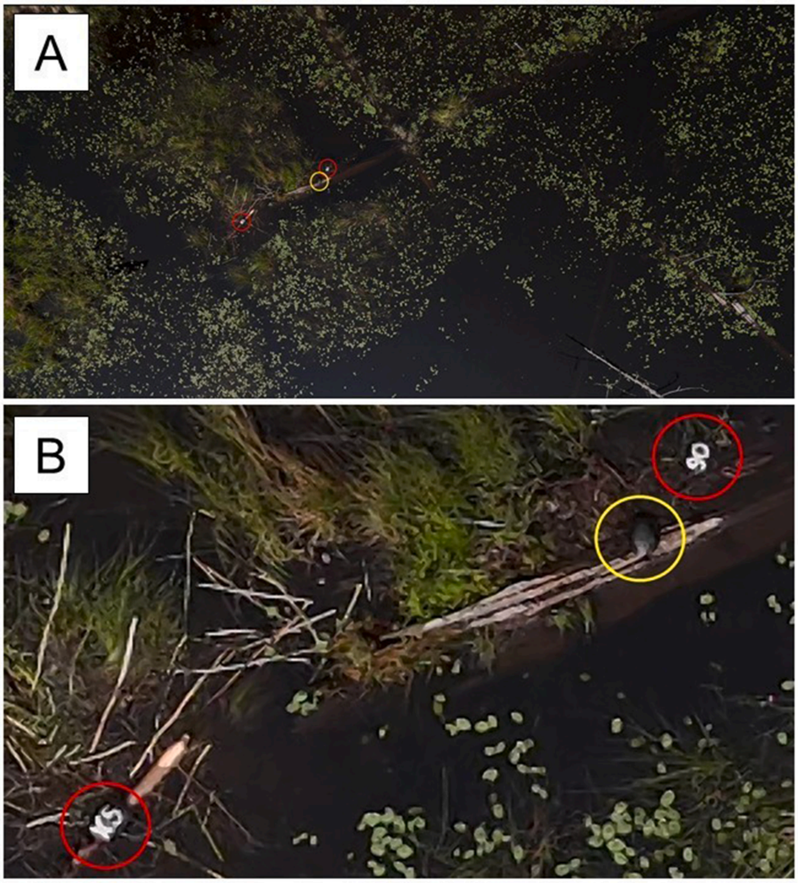

Fig. 7. A Screenshot of the drone footage from a study of painted turtle basking behaviour at Kenauk, Montebello, Québec, Canada, in 2025. The screenshot shows three basking turtles: X5 and O6 circled in red, and an unmarked turtle circled in yellow. Image A is an unzoomed screenshot from the drone footage. Image B is the screenshot zoomed in, showing how the turtles can be identified in drone footage review.

the turtle did not flee, we reduced the altitude to 15 m, and the drone hovered for 60 s. This process was repeated at 10 m and finally at 5 m, hovering for 60 s at each altitude (Fig. 8). If the turtle fled at any point, we recorded the drone altitude at the moment of fleeing as the FID and the test was terminated. A trial where the turtle that did not flee at any altitude was assigned an FID < 5 m. Tests were conducted between May and August, between 10:00 and 15:30.

We performed 50 FID tests. Of these, 34 tests were on marked turtles that we could identify, corresponding to 24 unique individuals, as some marked individuals were tested more than once, but on different days. The remaining 16 tests were on unmarked

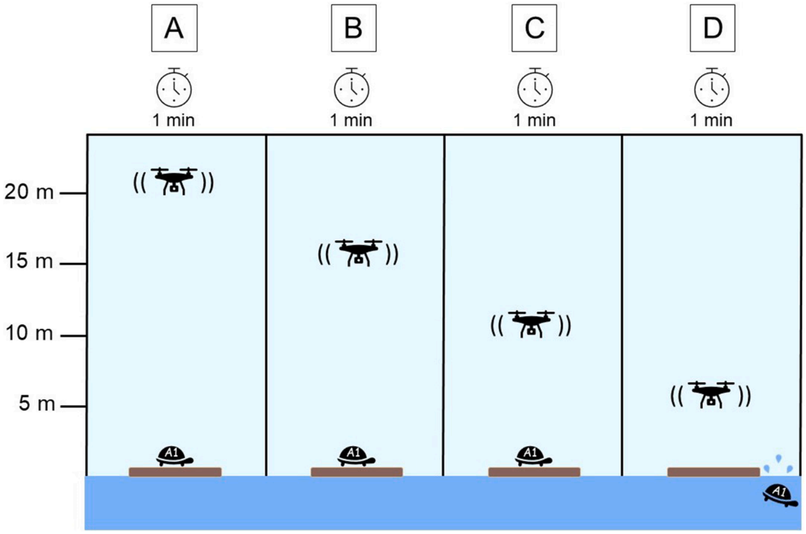

Fig. 8. Diagram of the method used to determine flight initiation distance with a drone in a study of painted turtle basking behaviour at Kenauk, Montebello, Québec, Canada, in 2025. We hovered the drone over a turtle at an altitude of 20 m for one minute, then descended to an altitude of 15 m and hovered for one minute, followed by 10 m for one minute and 5 m for one minute. We noted at which altitude the turtle fled, if ever, and used these data to inform the altitude at which we would fly the drone to survey turtles without altering their behaviour.

turtles. The full spreadsheet of FID data is provided in the supplementary material. We observed turtles flee in only 4 of the 50 tests (8 %). All four of the escape responses occurred at 5 m, the lowest altitude tested. The four turtles that fled included one unmarked individual, two males, and one female, and all were basking alone. Although all individuals that fled were basking alone, 31 of the 50 turtles tested were also basking alone, indicating that solitary basking was not a reliable predictor of escape behaviour. Because 46 of the 50 turtles did not flee at any tested altitude ≥5 m, we concluded that their FID was <5 m. Because the highest observed FID was 5 m, and because the majority of turtles tolerated drone presence at even lower FID thresholds, our monitoring protocol using a survey altitude of 15 m did not initiate an escape response and did not reduce the number of basking turtles during drone surveys. We recommend that similar FID tests be conducted by researchers implementing drone-based turtle surveys, as species differences, environmental conditions, and the drone model used may influence FID and should be considered when selecting an appropriate survey altitude.

Limitations

While this drone-based method for surveying freshwater turtle basking behaviour was overall successful, there are some limitations. The DJI Mini 4 Pro is not rain-tolerant and can only withstand wind speeds up to 10 m/s. Because our design involved continuous surveys over ∼12-hour periods at 20-minute intervals, data collection was strongly dependent on stable weather conditions. Survey days had to be selected such that there would be no rain or high winds for almost the entire day, not just during a short sampling window. In regions with frequent storms, high winds, or rapid weather changes, the requirement of stable weather conditions could reduce the number of sampling days.

Under realistic field conditions, we identified a safe flight duration of ∼30 min per fully charged battery. This was sufficient to survey a ∼44,345 m^2 wetland on a single programmed route. Surveying much larger areas, however, would require battery swaps mid-route or multiple flight plans. This would demand more batteries, additional charging capacity in the portable power source, and likely reduced sampling frequency if the survey duration exceeded the desired survey interval. Future technological improvements in battery capacity may partially reduce this constraint.

This drone-based survey method generates many hours of continuously recorded video, which is time-consuming to review manually. A single 18-minute survey could take up to one hour to review and extract the data when many turtles were present. Manual analysis also introduces the possibility of human error, as turtles may be missed or misidentified despite standardized reviewer training. Although occasional missed detections are unlikely to affect results meaningfully with such high sample sizes, automated detection and identification tools (e.g., machine learning) could substantially reduce processing time in future applications.

Finally, although the carapace paint markings were generally identifiable, some recordings were obscured by glare or motion blur, preventing the identification of certain individuals. In these cases, we logged a partial identification (e.g., known letter, but not number of the alphanumeric code) and revisited the identification during the next survey. The high temporal resolution (every 20 min) made retroactive correction feasible, as many turtles were still basking at the same location in the following survey, where they could be identified properly. If surveys were conducted at lower frequencies, however, or if the species of turtle being surveyed basked for shorter intervals, unidentifiable turtles could accumulate and reduce the precision of individual-level data.

Ethics statements

All protocols were approved by the University of Ottawa Animal Care Committee (protocol BLF-4401-A1) and conducted under a scientific permit issued by the Ministère de l'Environnement, de la Lutte contre les changements climatiques, de la Faune et des Parcs du Québec (permit 2025–07-SF-001-GR-0). The protocols complied with the ARRIVE guidelines.

Related research article

None.

For a published article

None.

CRediT authorship contribution statement

Lauren Dobie: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Visualization, Supervision, Project administration, Funding acquisition. **Gabriel Blouin-Demers:** Resources, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.mex.2026.103791.

Data availability

The data used in this article is available in the supplementary material.

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