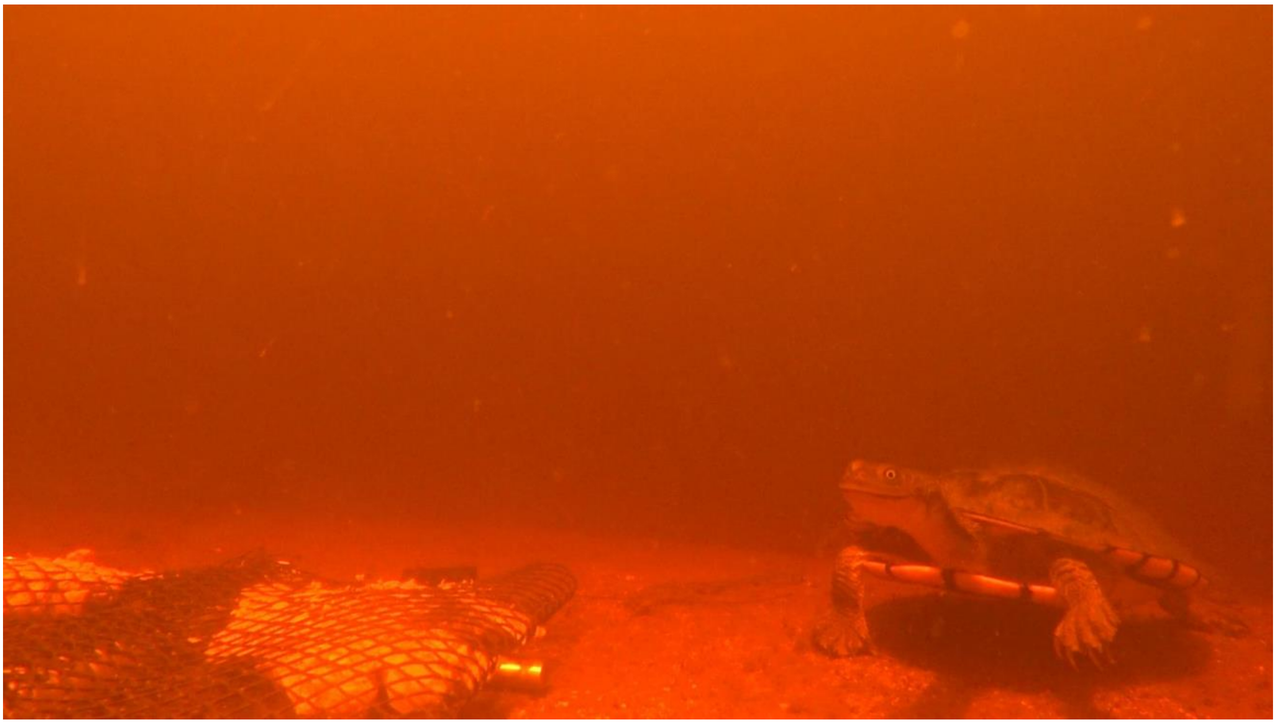
INNOVATION IN WATER SCIENCE

Using baited remote underwater videos to monitor freshwater turtles – a pilot study

Headwaters of the Namoi, Gwydir and Border Rivers valleys

August 2021



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Cover image: An Eastern long-necked turtle caught recorded on an underwater video camera by Daniel Coleman

Acknowledgment of Country

The Department of Planning, Industry and Environment acknowledges the Traditional Owners and Custodians of the land on which we live and work and pays respect to Elders past, present and future.

Contents

Summary

Freshwater turtles play an important ecological role in river environments in New South Wales (NSW). They are long-lived, charismatic animals that contribute to improved water quality and nutrient cycling by scavenging (Santori et al. 2020) (Figure 1). NSW has 7 native species of freshwater turtle, 3 of which are listed as endangered or critically endangered under the NSW *Biodiversity Conservation Act 2016*.

To survive and thrive, these species rely on healthy river environments. However, the management of water resources for ecosystem outcomes has tended to focus on a handful of iconic species, notably native fish.

Freshwater turtles have suffered from a relative neglect, which is largely an artefact of limited research. Comparatively little is known about the outcomes of water management on turtle populations. Turtles are long-lived, grow slowly, and exhibit varied life-history characteristics, which can make it difficult to detect impacts to their populations in the short term (Singh 2018).

Figure 1. An Eastern long-necked turtle (*Chelodina longicollis*) filmed on a baited remote underwater video in the upper Gwydir River

In NSW, we manage the health of rivers through catchment-scale water sharing plans developed under the NSW *Water Management Act 2000.* Water sharing plans aim to protect and enhance river ecosystems, including vulnerable aquatic populations such as freshwater turtles. By monitoring population extent and abundance of turtles, we can better understand whether management actions are effective.

The need for a new monitoring method

There are many traditional methods for monitoring freshwater turtles. One of the most common is 1 metre wide and 2 metres high baited cathedral traps (Figure 2b). While useful for mark and recapture, measurements, sexing and checking individuals for disease, these traps require long sampling times and may cause some degree of distress to target and non-target animals (such as Platypus). In addition, the capture rates of small individuals (juveniles and hatchlings) in some species (such as Bell's turtles, *Myuchelys bellii*) are low (Ream and Ream 1966, Chessman 2015) and there is some evidence of trap shyness due to low recapture rates (L. Streeting 2019, pers. comm., 21 Jan).

Testing new and innovative techniques that are less resource intensive and less invasive will provide a new tool for scientists to track changes in turtle populations.

Baited remote underwater video systems (BRUVs) (Figure 2a) use video recordings set behind a bait attractant to collect images of animals. BRUVs are widely used in marine environments as a relatively cheap, non-extractive method of surveying fish assemblages (Whitmarsh et al. 2017).

Despite the benefits of this technique, its application to freshwater environments has been limited (Ebner and Morgan 2013, Ebner et al. 2015, Schmid et al. 2017). To our knowledge, only one study has assessed the usefulness of BRUVs to monitor freshwater turtles (Schmid and Giarrizzo 2019).

Our study

We trialled the use of BRUVs on turtle populations in the Northern Tablelands of NSW. This included 7 rivers known to have records of the endangered Bell's turtle (*Myuchelys bellii*), as well as populations of Eastern long-necked turtle (*Chelodina longicollis*) and Macquarie River turtle (*Emydura macquarii*).

This is the first time that BRUV technology has been used to target freshwater turtles in Australia. The outcomes of this study will assist in refining this technique for broader use. The main aims of the project were to:

- test if BRUVs were useful tools for sampling freshwater turtles (abundance, size and sex)
- assess if BRUVs could attract young turtles, which are often underrepresented by traditional trapping methods
- identify any variables that may influence the success of BRUV sampling to provide options for improvement in the future.

Our findings

- We successfully identified all 3 species known to occur in the study sites and produced relative abundance measures similar to traditional trapping techniques.
- BRUVs did not capture any hatchling or small turtles on camera, which suggests that juveniles were either absent, rare, or are not sampled well with BRUV methods.
- Visibility is a key consideration when using BRUVs. Ideally, turbidity should be below 10 FNU in shallow environments (less than 2 metres) or below 5 FNU at greater depths.
- Sixty minutes is sufficient sampling time for freshwater turtles, with rarer species like the Bell's turtle taking the longest time to arrive at a bait.

Impact on future freshwater turtle monitoring

BRUVs can provide a non-invasive and relatively easy method to monitor relative abundance of freshwater turtles in coastal streams and inland headwaters where turbidity levels are relatively low. This makes them a useful tool for long-term turtle monitoring programs like those required to assess the ecological outcomes of Water Sharing Plans, especially when resourcing of capture-recapture methods is not feasible.

Three turtle species are identified as drivers of ecological risk due to water resource development in NSW and will require some form of monitoring. These include the Bellinger River turtle, the Bell's turtle and the Manning River turtle.

With some modifications to their design, BRUVs could also provide consistent and accurate measurement and sexing of freshwater turtles. Modifications could include a minimum distance of 60 centimetres between bait and camera, downward facing cameras for carapace measurement, and attaching a ruler to the bait bag to categorise lengths into coarse size classes.

Project details

Freshwater turtles and water management in NSW

New South Wales (NSW) is home to 7 native species of freshwater turtle, 3 of which are listed as endangered or critically endangered (under the NSW *Biodiversity Conservation Act 2016*). The Bell's turtle, *Myuchelys bellii* (Gray, 1844), also known as the western saw-shelled turtle and Namoi River snapping turtle, is endemic to northern NSW and far south-eastern Queensland (Chessman 2015). The species is limited to 4 separate NSW sub-populations in the Namoi, Gwydir, Severn and Deepwater river systems, and one in Bald Rock Creek in QLD (Chessman 2015, Fielder et al. 2015a). It is listed as nationally vulnerable under the *Environment Protection and Biodiversity Act 1999* Cth (under *Wollumbinia bellii*) and as endangered in NSW under the *Biodiversity Conservation Act 2016* NSW.

In NSW, we manage water under the *Water Management Act 2000* NSW. The Act and its associated water sharing plans establish environmental objectives for water management, including to protect river ecosystems and the biodiversity within them. The Water group at NSW Department of Planning, Industry and Environment leads monitoring, evaluation and reporting of the state's rivers to test water sharing plans against these environmental objectives.

Historically, freshwater turtles have not been a focus of monitoring or water management decisions for the department. Turtles have also received very little scientific attention compared to other animals like fish. As such, there is limited understanding of the flow requirements for turtles and whether water sharing plans in NSW effectively protect them. To address this knowledge gap, we need continued monitoring of threatened and non-threatened turtles to better understand species distribution, ecology, and potential threats from water resource development.

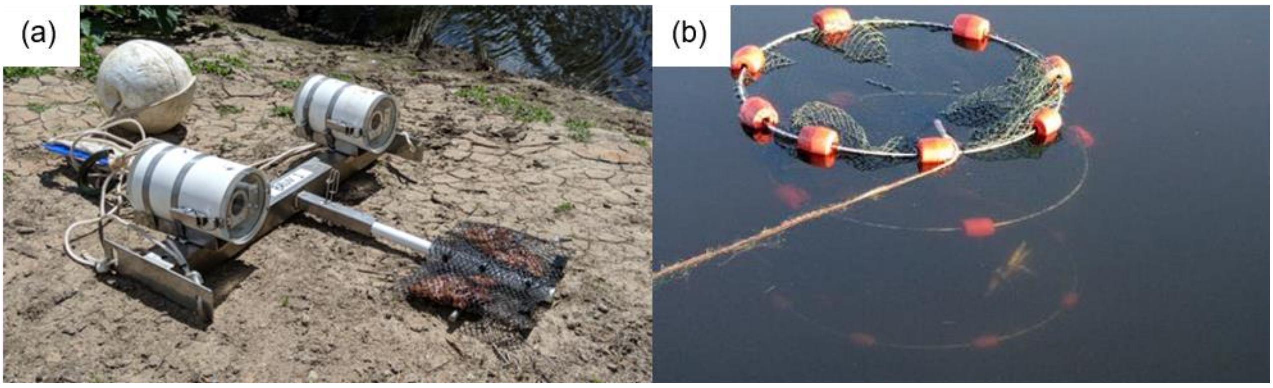

Figure 2. (a) Image of the stereo baited remote underwater video setup with bait bag and liver bait and (b) an example of a cathedral trap (photo: University of North Dakota) traditionally used to sample freshwater turtles

Sample sites and study design

Sampling with baited remote underwater videos

The target species for this study were the endangered Bell's turtle (*Myuchelys bellii*), Eastern long-necked turtle (*Chelodina longicollis*), and the Macquarie River turtle (*Emydura macquarii*). We sampled (ethics authority AEC19-094) between 12 and 19 March 2020 at 7 sites known to be inhabited by these species. We only used samples from 5 sites (Figure 3) as the other 2 sites were deemed unusable due to high turbidity from recent rainfall.

At each of the 5 sites, we dropped 4 BRUVs randomly at least 100 metres apart and left them for approximately one hour. We sampled at a range of depths (0.2 to 2.5 metres) and pool microhabitat types (riparian overhang, sedge, silt, sand, cobble, boulder, snag or weed). Sampling was repeated 3 times (morning, midday and afternoon) at 3 sites and 2 times (morning and midday) at 2 sites, resulting in a total of 51 samples (approximately 51 hours of footage) across all sites and time periods.

The BRUV setup had 2 cameras (Sony FDR-X3000) in waterproof casings, allowing for stereo measurements of lengths, and a mesh bait bag that draws turtles close to the camera. We baited each camera with 200 grams of fresh sheep liver. We retrieved the BRUVs after approximately one hour. At each site, we recorded water turbidity, temperature, electrical conductivity, pH, and dissolved oxygen content (% and mg/L) using a Hanna multiparameter water quality meter (HI-9829-13042) to characterise sites and determine if water quality conditions affect sampling quality.

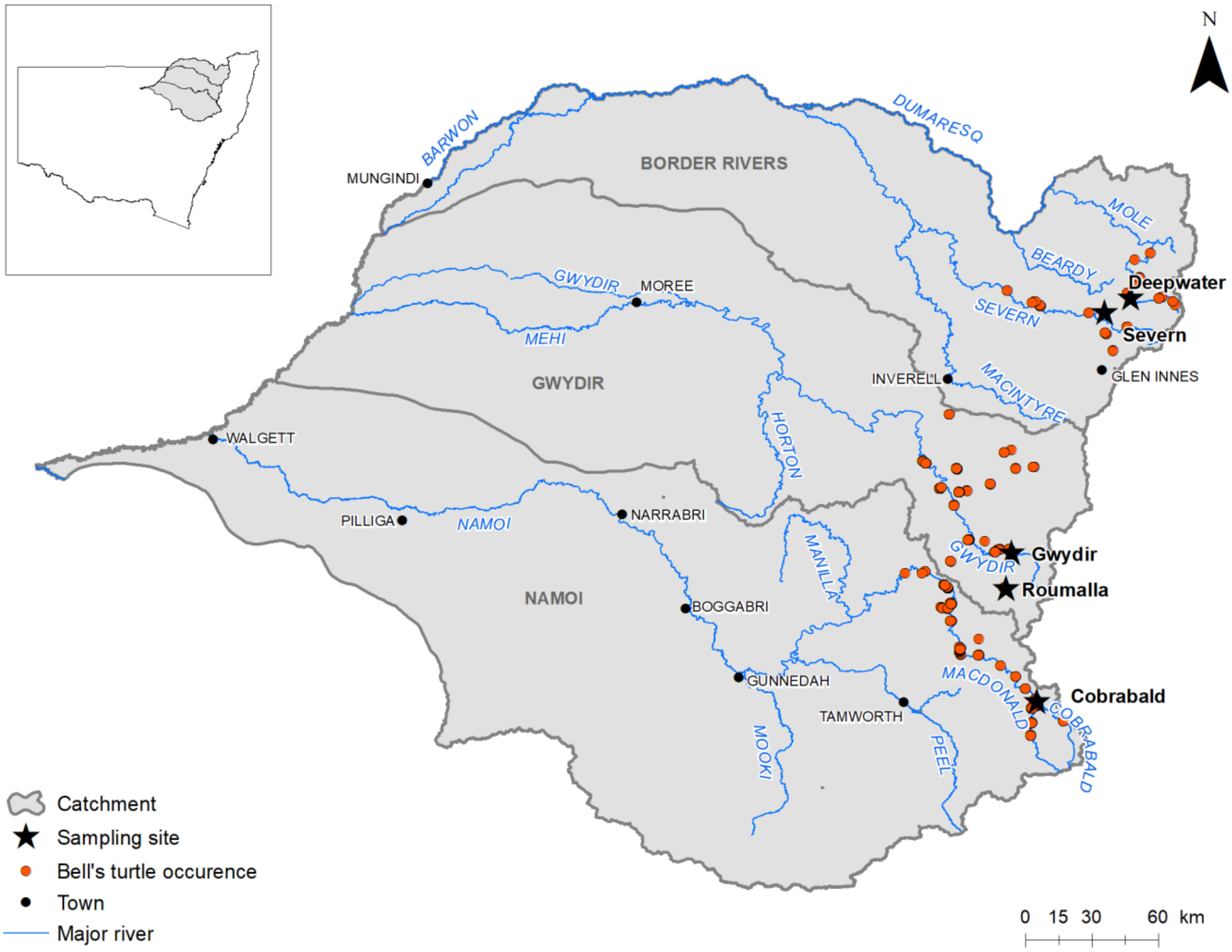

Figure 3. Map of study sites, catchments, and records of Bell's turtle (*M. bellii*) occurrence (occurrence records sourced from bionet.nsw.gov.au)

We processed the footage using EventMeasure software (SeaGIS). Samples were standardised to 60 minutes of footage. For each sample, we recorded:

- the time of first appearance by a species
- the relative abundance (MaxN) (within a species and in total) visible across both cameras at any one time
- the time of MaxN (for individual species only)
- species diversity.

MaxN is a commonly used conservative measure of species' relative abundance in BRUV analyses because it avoids double-counting (Osgood et al. 2019). MaxN does not reflect the total number of individuals that may have visited the BRUV at different times during its deployment. As each camera was separated by approximately 100 metres, we pooled the 4 measures of MaxN from each sampling time into one relative abundance measure (TotalN) to produce a single, combined measure for morning, midday and afternoon.

Sampling with traditional methods

Additional abundance data was collected using cathedral traps as part of a long-term monitoring project being undertaken by the Turtles Forever project. Northern Tablelands Local Land Service kindly provided the data. The abundance data was from 3 of the pools (sites) used in this study and was collected within one month of the sampling period used in this study. At each site, 10 cathedral traps were baited with sheep liver and set overnight with a deployment time of 12 hours. The total number of turtles was pooled across all 12 traps.

More details on the methods and the data analysis used are in Appendix A.

Results

Effectiveness of remote underwater videos for sampling turtles

Estimating turtle diversity and abundance

We successfully detected all 3 species of turtles known to occur within this region, including the endangered *M. bellii* (Figure 4).

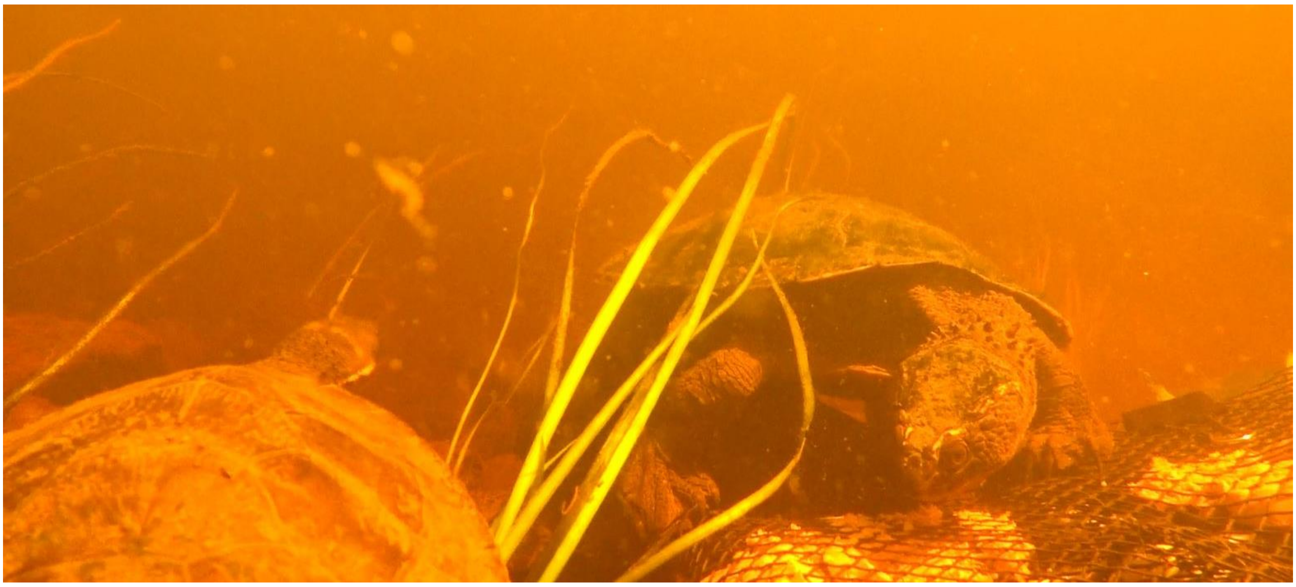

Figure 4. The endangered Bell's turtle recorded feeding in Deepwater River as a Macquarie River turtle swims by

Across all 51 samples collected from 5 sites, the highest total abundance (TotalN) for all species was recorded during the morning (before 9 am). There were 34 turtles identified from 16 morning samples, 21 turtles from 19 midday samples, and 28 from 16 afternoon samples. The highest relative abundance (MaxN) on one BRUV was 5 for the Macquarie River turtle (Figure 5), 4 for the Eastern long-neck turtle and 2 for the Bell's turtle. The highest total number of turtles pooled across the 3 species was 6, with 5 Macquarie River turtles and one Bell's turtle in one image.

Measuring and sexing turtles using BRUVs

Stereo BRUV setups using 2 calibrated cameras provide the ability to measure organisms underwater. We used stereo setups to test if we could accurately measure freshwater turtles using BRUVs. This would enable population structure data (size and sex ratios) to be incorporated into future monitoring projects. We were only able to measure 13 individuals.

The carapace size (turtle shell length) of the 13 measured turtles ranged from 140 millimetres to 250 millimetres. The accuracy of measurements was limited by:

a) the proximity of the turtle to the camera (an individual must be visible in full on both cameras to be measured)
b) low visibility due to high turbidity
c) inherent issues in measuring round carapaces (making it difficult to determine a start and end point).

Improvements to the BRUV design may alleviate issue (a) and (c), while avoiding highly turbid periods will assist with overcoming (b).

We were able to sex 26 turtles – 7 Bell's turtles (4F: 3M), one Eastern long-necked turtle (0F: 1M) and 18 Macquarie River turtles (9F: 9M). The ability to sex freshwater turtles was reliant on the angle a turtle moved within the camera frame as the size of the tail is an indication of sex for most species. Identifying the sex of the Eastern long-necked turtle was more difficult and would be better determined using mark–recapture methods.

Figure 5. (a) An image of a BRUV deployed near a snag in Deepwater River and (b) an image of the maximum abundance (MaxN) for Macquarie River turtle from a morning BRUV at Deepwater River

BRUVs compared to cathedral traps

We compared data collected from the same season and the same 3 sites using BRUVs and baited cathedral traps. Cathedral traps recorded more turtles at 2 of the 3 sites. However, the sampling effort used for cathedral traps was far greater (10 traps for 12 hours) than for BRUVs (4 BRUVs for 4 hours). We used the number of turtles per trap-hour as a catch-per-unit effort estimate for cathedral trap data. For BRUV data, we used the MaxN, which is a conservative measure of relative abundance as it avoids double counting (Osgood et al. 2019). The number of turtles per trap-hour and MaxN provided a relative abundance estimate for each method and the 2 species present (Bell's turtle and Eastern long-necked turtle).

Using an analysis of variance, we found that the relative abundance for morning BRUVs, midday BRUVs, and afternoon BRUVs were not significantly different for the Bell's turtle and the Eastern long-necked turtle (Figure 6, $F_{(2,64)} = 1.56$, $p = 0.22$). However, there was a difference between species ($F_{(1,64)} = 13.5$, $p = 0.000$). BRUVs performed particularly well for the rarer species – the Bell's turtle. Most Bell's turtles were recorded on morning BRUVs, with an average MaxN of 0.58 (SD = 0.51) (Figure 6). This was similar to cathedral traps, with 0.54 (SD = 0.33) turtles per trap-hour. However, the site where cathedral traps performed the best had the highest turbidity, which also contributed to reduced detection on BRUVs, increasing the possibility of reduced abundance estimates.

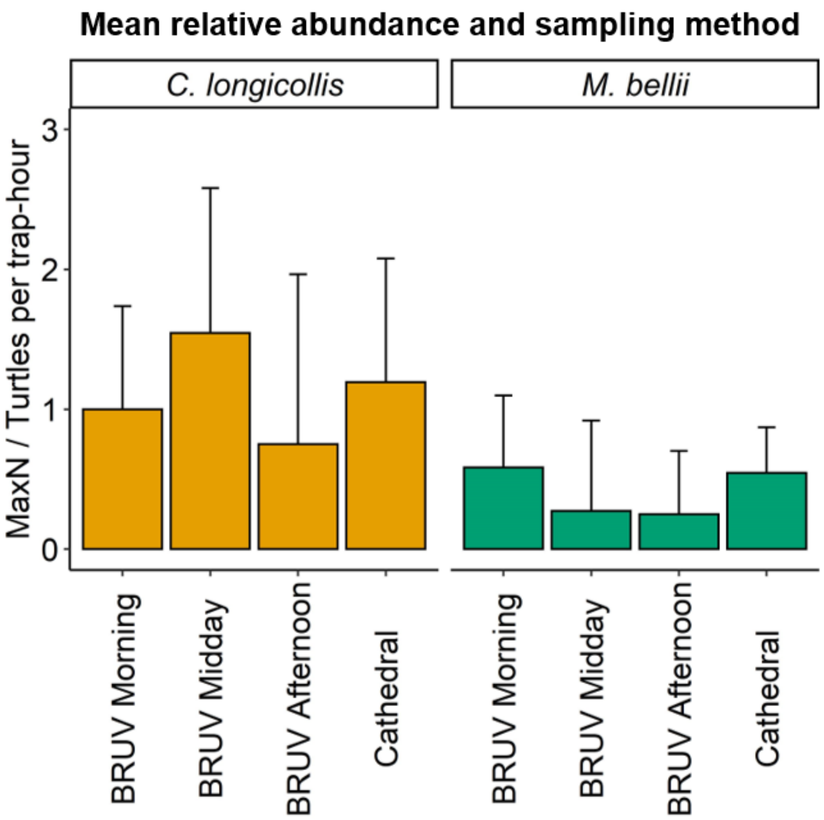

Figure 6. Mean relative abundance (+1 one standard deviation) for the Eastern long-necked turtle (*C. longicollis*) and the Bell's turtle (*M. bellii*)

MaxN is the relative abundance measure for the baited remote underwater videos (BRUV) sampling method while turtles per trap-hour is presented for cathedral traps. The sample size (number of BRUVs and cathedral traps) was 12 for morning and afternoon BRUVs, 11 for midday BRUVs and 30 for cathedral traps. Data is from the 3 sites Cobrabald, Roumalla and Gwydir.

Modelling turtle populations using BRUV data

The certainty around detection of cryptic and rare animals is a key consideration in assessing biodiversity and population size. The use of occupancy models (for example the Bayesian hieracrchical model for animal occurence and abundance [Unmarked Bayesian Models with Stan – ubms]) can provide population abundance and occupancy (presence/absence) predictions based on the probability of detection.

We used ubms to develop a model to predict turtle abundance for each species at each site based on the total number (TotalN) of turtles recorded by BRUVs at each site. Sampling time, turbidity and maximum pool depth were used as covariates. The best model for abudance predictions for all

3 species included all 3 covariates, however depth was the best predictor (Appendix A – Table A 2, Table A 3 and Table A 4). Higher abundances were associated with deeper pools for the Bell's turtle and the Macquarie River turtle (Figure 7). For the Bell's turtle only, detection probability reduced with time of day and increased with turbidity. Table 1 shows the predicted abundance of each species at each site.

This pilot shows that incorporating occupancy models like ubms is useful to estimate population abundances for turtles sampled with non capture–recapture (unmarked) methods like BRUVs. The collection of data across more sites, species, and detection factors would improve the ability of occupancy models to predict abundances and help us understand the detection probabilities (for example the influence of the time of day) that can influence the accuracy of population estimates.

Table 1. Total number of turtles (TotalN) observed using BRUV and cathedral traps, and the number of predicted turtles (with 5%, 95%confidence intervals) from BRUV data using the Bayesian hieracrchical model for animal occurence and abundance (ubms)

The BRUV observed value represents the highest number of turtles at a site, pooled across 4 BRUVs for either morning, midday or afternoon. *n* = number of samples. Roumalla Creek is highlighted blue as the BRUVs performed poorly due to high turbidity at this site.

Site	Mean turbidity	Estimate	*C. longicollis*	*E. macquarii*	*M. bellii*
Cobrabald River	14.1	BRUV observed (*n*=4)	5	0	2
Cobrabald River	14.1	Cathedral observed (*n*=12)	3	0	2
Cobrabald River	14.1	BRUV predicted	7.5 (3.8, 13.4)	0.1 (0.0, 0.4)	2.4 (0.8, 5.6)
Deepwater River	2.1	BRUV observed (*n*=4)	0	14	3
Deepwater River	2.1	Cathedral observed (*n*=12)	No data	No data	No data
Deepwater River	2.1	BRUV predicted	1.8 (0.2, 4.9)	15.3 (7.0, 24.5)	5.3 (1.3, 15.3)
Roumalla Creek	18.3	BRUV observed (*n*=4)	3	0	2
Roumalla Creek	18.3	Cathedral observed (*n*=12)	28	0	10
Roumalla Creek	18.3	BRUV predicted	4.3 (2.0, 8.2)	0.4 (0.02, 1.4)	2.9 (1.3, 5.6)
Severn River	3.4	BRUV observed (*n*=4)	2	0	0
Severn River	3.4	Cathedral observed (*n*=12)	No data	No data	No data
Severn River	3.4	BRUV predicted	8.3 (4.0, 15.2)	0.07 (0.00, 0.3)	2.3 (0.7, 5.6)
Gwydir River	4.5	BRUV observed (*n*=4)	9	0	3
Gwydir River	4.5	Cathedral observed (*n*=12)	16	0	9
Gwydir River	4.5	BRUV predicted	5.2 (2.7, 9.7)	0.2 (0.00, 0.9)	2.7 (1.1, 5.5)

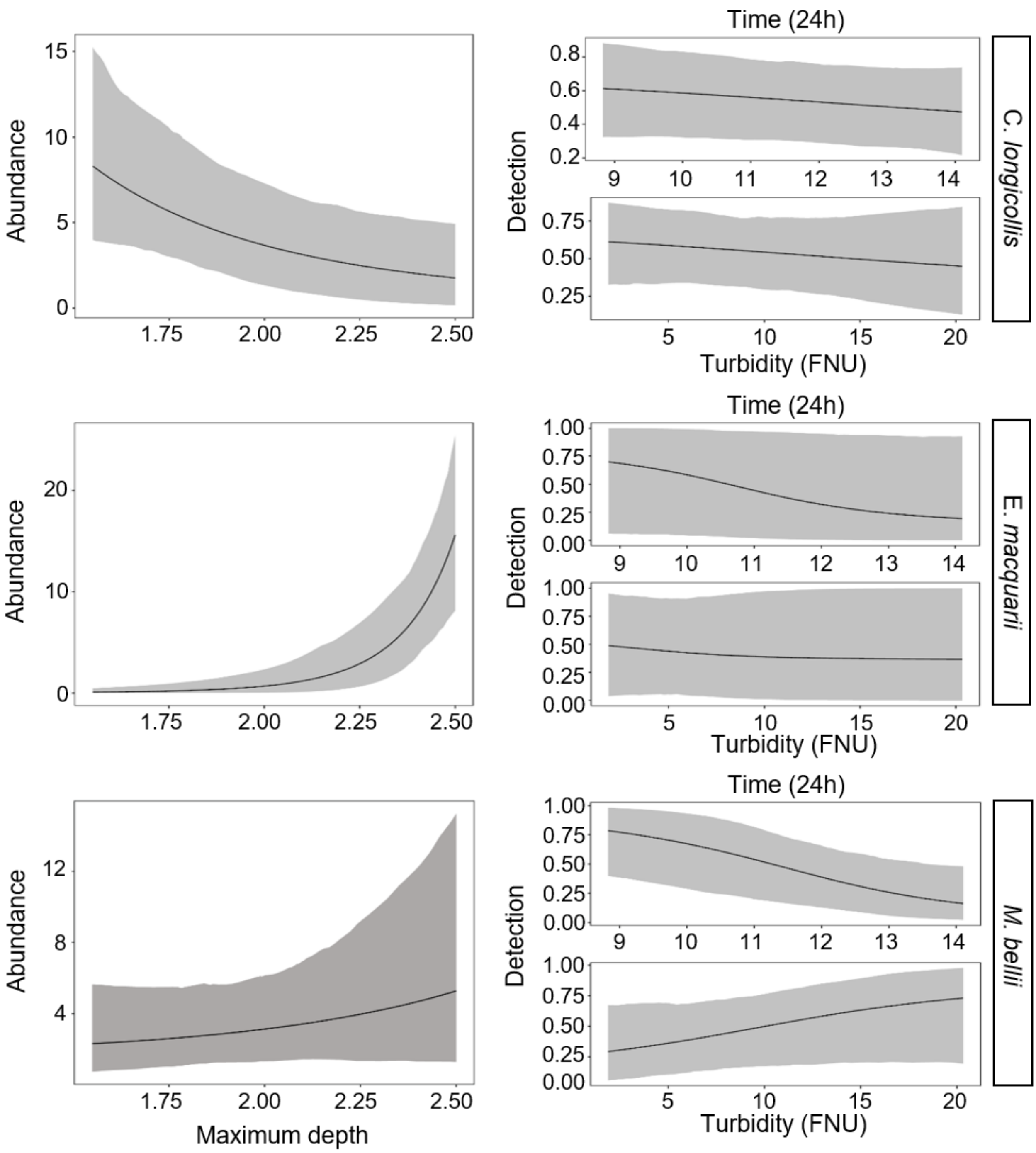

Figure 7. Abundance estimates (total number of turtles, TotalN) based on maximum pool depth and detection probabilities (likelihood of detecting each species) associated with sample time (24 hours) and turbidity (FNU) for each turtle species – grey shaded areas represent the 5%, 95%confidence intervals

Detecting young turtles with BRUVs

The detection of smaller or young turtles (classified in this study as turtles with a carapace less than 100 millimetres shell length) with cathedral traps is low (Ream and Ream 1966, Chessman 2015). Cathedral traps have 2 potential limitations that may be overcome by BRUVs.

Ideally, cathedral traps require deeper water but can be used at depths of 0.2 metres. This may not be the preferred foraging habitat if the increased risk of predation from fish and larger turtles deters young turtles from foraging in open, deep water habitat. Also, cathedral traps are large (around

1 metre by 2 metres), conspicuous objects that often attract other predators/scavengers. Both reasons may contribute to the reduced capture rates of young turtles by cathedral traps.

In contrast, BRUVs can be deployed at a depth of 0.2 metres or more. They are also relatively small and inconspicuous. Therefore, we expected to have some detection of young turtles using BRUVs.

To ensure we maximised our chance of detecting young turtles, we included a range of microhabitats and depths. We sampled macrophytes (reeds and weed beds), snags, riparian overhands, boulders, cobbles, sand and silt. The sampling depth was less than 0.5 metres deep for 20% of BRUVs, 37% were at a depth of 0.5 to 0.99 metres, and the remainder (43%) were deeper than 1.0 metre.

While we were only able to accurately measure 13 turtles, the length of the bait bag (200 millimetres) and shell morphology (for example a raised keel/ridge on the shell) provided a secondary assessment of whether individuals were hatchlings or smaller juveniles.

We detected no turtles less than 100 millimetres (for any species) on the 51 BRUV videos. One of the smallest turtles was a Bell's turtle around 150 millimetres long (carapace length) (Figure 8). It is possible that hatchling and smaller turtles are not attracted to the typical meat-based baits (such as sheep liver), or there may be other factors that reduce the ability to sample young turtles, and thus estimate annual recruitment.

Future work should target areas where large numbers of captive bred turtles are released and try alternative baits and survey methods to establish an effective method for sampling hatchling and small juvenile turtles.

Figure 8. One of the smallest turtles captured on a BRUV in this study was this Bell's turtle (~150 millimetre carapace) in the upper Gwydir River

Lessons learnt from this pilot study

We identified several factors that influence the success of BRUVs and that should be considered when using BRUVs for freshwater turtles in the future. These include:

- how long BRUVs should be deployed (sampling duration)
- visibility limitations
- other sampling considerations
- insights into turtle behaviour using BRUVs.

How long BRUVs should be deployed

We used 60-minute video recordings in this pilot study. Based on the time until maximum relative abundance (MaxN) was reached, 60 minutes is a sufficient sampling period. The average time required to reach MaxN was similar for all 3 species: 34 minutes (SD = 16) for Eastern long-necked turtles, 42 minutes (SD = 13) for Macquarie river turtles, and 41 minutes (SD = 15) for Bell's turtles (Figure 9). The time till first appearance for each species provides a measure of how fast a species is first observed on the camera.

In some animals, a shorter time until first appearance is correlated with a higher relative abundance (Stobart et al. 2015). It can also be related to the distance travelled for a species to get to the BRUV or how attracted to the bait they are (Whitmarsh et al. 2017).

In this pilot study, we found that Macquarie River turtles were the fastest to appear. There was an average of 13 minutes (SD = 3) before at least one individual arrived (Figure 9). This species also had a high abundance in the sampling site where the species occurred (Deepwater River).

The endangered Bell's turtle took the longest time to appear, 39 minutes (SD = 13) on average, and had the lowest MaxN. While not conclusive, this suggests that the time until first appearance in freshwater turtles may be related to population abundance or rarity.

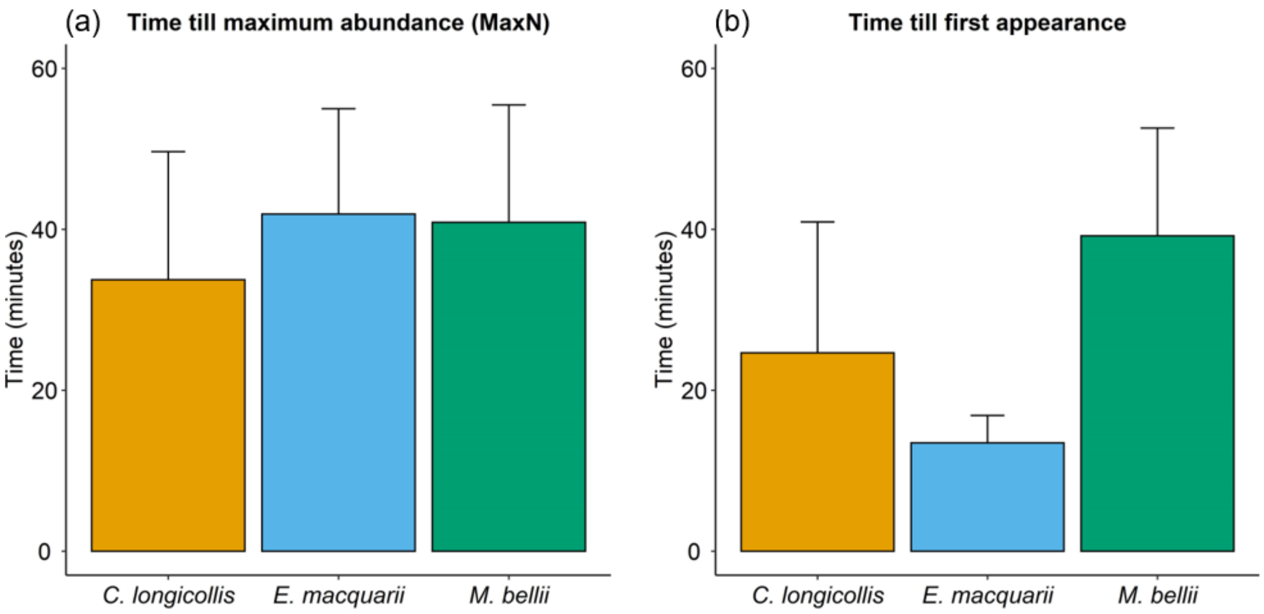

Figure 9. (a) Time till maximum abundance (MaxN) and (b) time till the first turtle appeared (first appearance) for the Eastern long-necked turtle (*C. longicollis*), Macquarie River turtle (*E. macquarii*), and the Bell's turtle (*M. bellii*)

Visibility limitations – depth and turbidity

One key consideration when using BRUVs is water clarity and the ability to see organisms clearly for identification, measurement, sexing and relative abundance counts. Depth and turbidity are 2 parameters that influenced the visibility of the BRUVs in this study. We measured turbidity (FNU) and depth (metres) at the location of all 51 BRUVs. We used this information to do a qualitative assessment on what turbidity and depth thresholds should be considered when using BRUVs in the future.

We were able to identify the species of turtle and sex at turbidity levels as high as 15 FNU, but the reduced clarity meant that our estimates of relative abundance (MaxN) may have been influenced by the reduced visibility distance, with only turtles close to the camera being recorded. Further, length measurements were not possible as the calibration of stereo BRUVs does not accurately measure individuals close (50 centimetres or closer) to the cameras. We suggest that future freshwater BRUV work should target streams and conditions where turbidity is less than 10 FNU for the best results.

Another consideration is the depth of the BRUV placement. The deepest deployment in this project was 2.5 metres. This was in a pool with relatively low turbidity (approximately 2 FNU) and good visibility. However, the pool was heavily tannin stained, which resulted in very little light penetration at the sampling depth. Visibility was still reasonable in this instance due to the low turbidity, but other sites where turbidity was higher resulted in unusable videos at greater depths. While it is difficult to suggest a maximum depth for BRUV use, we recommend avoiding deployments deeper than 2 metres in tannin-stained environments or where turbidity levels are greater than 5 FNU. Clearer coastal streams with less tannins would allow deeper deployments.

Other sampling considerations

BRUVs are traditionally restricted to daytime use, although some researchers have used artificial lights for nocturnal species (such as Fitzpatrick et al. 2013). Understanding the best time to sample freshwater turtles may improve the detection rates of certain species.

We incorporated the time of day into the occupancy model for all 3 turtle species. This produced a detection probability between zero and one. Higher detection probabilities indicate a better time for sampling turtles using BRUVs. Based on the 95% uncertainty intervals, the time of day is negatively correlated with detection for Bell's turtles but not the other 2 species (Figure 7). This suggests that targeting early mornings for BRUVs is best for Bell's turtles but may not be a consideration for Eastern long-necked turtles and the Macquarie River turtles. This study did not sample in the late afternoon (around dusk) or at night-time using lights. This is an area for future research and may prove more effective for freshwater turtle detection.

Changes to the BRUV design may also improve the ability for future projects to measure more individuals. Many turtles were too close to the cameras to get an accurate measurement with the calibrated stereo cameras. We suggest that the traditional horizontal BRUV design that we used in this project needs to have the bait bag 60 centimetres or more from the camera.

An additional consideration is the shape of turtle shells. The oval shape, and the difficulty getting a good angle for measuring the carapace length reduced our ability to confidently measure several turtles. Using a downward-facing (vertical) BRUV system may overcome this issue as it would provide a view of the carapace from above the turtle. Vertical BRUVs are commonly used in marine environments and can be constructed with minimum resources. If accurate measurements are not required, a ruler or measuring object could be placed parallel or perpendicular to the bait bag (Whitmarsh et al. 2017). This would provide coarse size measurements and allow turtles to be classified by size classes (for example 0–5 cm, 5–10 cm, 10–15 cm and so on). It would also double the sample size and reduce sampling effort as you would only need one camera per BRUV setup.

Insights into turtle behaviour using BRUVs

A study by Chessman (2015) on Bell's turtles suggests that this species has a negative association with Macquarie River turtles, which may be due to competition from the dietary overlap in the 2 species, and the growth rate, size and fecundity of Macquarie River turtles (Spencer 2002, Fielder et al. 2015b). The invasion of Macquarie River turtles into the range of the endangered Bell's turtles is considered a key threat to the future of the species.

BRUV recordings of turtles competing for a food resource in their natural habitat may provide some insight into competitive interactions among and between turtle species. We documented Bell's turtles and Macquarie River turtles interacting on 4 separate BRUV deployments at the Deepwater River site. Macquarie River turtles were more abundant (Table 1), arrived sooner (Figure 9a) and were much more active around the bait. Further, this site was the only site with Macquarie River turtles present and the only site that had noticeable damage to the bait bag when BRUVs were collected.

It was also evident that Macquarie River turtles was extremely aggressive towards the bait on the video recordings, but not towards other Macquarie River turtles or Bell's turtles. Notably, once a Bell's turtle arrived on screen, it often took the closest position to the bait and remained on screen, undisturbed by any Macquarie River turtles. In one instance, 5 Macquarie River turtles were actively feeding on the bait while a smaller (approximately 150 millimetre) Bell's turtle was still gaining access to the bait.

These observations suggest that Macquarie River turtles may be more active around resources, particularly carrion, but do not interfere with Bell's turtles' ability to access the same food resource. If resources were limited, the speed of arrival and abundance of Macquarie River turtles may contribute to a competitive dominance over Bell's turtles.

This pilot was not a behavioural study, and therefore lacks the design to quantify and test these interactions effectively. However, it does highlight that BRUVs can be a useful tool for behavioural observations in freshwater turtle species.

Conclusions

We conclude that BRUVs provide a useful tool for surveying populations of freshwater turtles where visibility is appropriate. They provide a non-invasive, relatively cost-effective and time-efficient way to collect relative abundance and species diversity data.

Monitoring of freshwater turtle populations using BRUVs should be considered given the requirement for NSW to monitor aquatic ecosystems to allow adaptive management to protect, enhance and restore water sources (*Water Management Act 2000* NSW). Turtle species considered at risk to further population decline and are target ecological populations for water sharing plan monitoring include:

- Bellinger River turtle (critically endangered, NSW and Commonwealth)
- Bell's turtle (endangered NSW, vulnerable Commonwealth)
- Manning River turtle (endangered in NSW).

BRUVs are also an excellent education tool as they produce video content that can be used to promote research and species conservation. They are a less effective method for measurements, sexing and disease identification compared to traditional capture–recapture techniques like the cathedral trap. BRUVs were not successful at detecting small turtles and are also not recommended when visibility is a key consideration, for example in many lowland streams of the Murray–Darling Basin.

Recommendations for future monitoring

We recommend that BRUVs be considered for future monitoring:

- in conditions where turbidity is below 10 FNU in shallow environments (less than 2 metres) or below 5 FNU at depths greater than 2 metres
- in coastal streams where turbidity levels are low, for example used for the critically endangered Bellinger River snapping turtle (*Myuchelys georgesi*) and the endangered Manning River turtle (*Myuchelys purvisi*) (*Biodiversity Conservation Act 2016* NSW)
- in headwater catchments of inland streams due to their relatively low turbidity levels during stable conditions
- when relative abundance is a satisfactory measure for the monitoring project
- to identify habitat preferences
- to investigate interactions within and between turtle species and other organisms.

More information

For more information on the findings of this report, contact the following Department of Planning, Industry and Environment staff via email.

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References

Chessman, B. C. 2015. Distribution, abundance and population structure of the threatened western saw-shelled turtle, *Myuchelys bellii*, in New South Wales, Australia. Australian Journal of Zoology 63:245–252.

Ebner, B. C., C. J. Fulton, S. Cousins, J. A. Donaldson, M. J. Kennard, J.-O. Meynecke, and J. Schaffer. 2015. Filming and snorkelling as visual techniques to survey fauna in difficult to access tropical rainforest streams. Marine and Freshwater Research 66:120.

Ebner, B., and D. Morgan. 2013. Using remote underwater video to estimate freshwater fish species richness. Journal of fish biology 82:1592–612.

Fielder, D., B. C. Chessman, and A. Georges. 2015a. *Myuchelys bellii* (Gray 1844) – Western Saw-shelled Turtle, Bell's Turtle. Chelonian Conservation Monographs 5.

Fielder, D., D. J. Limpus, and C. J. Limpus. 2015b. Reproduction and population ecology of the vulnerable western sawshelled turtle, *Myuchelys bellii*, in the Murray–Darling Basin, Australia. Australian Journal of Zoology 62:463–476.

Fitzpatrick, C., D. McLean, and E. S. Harvey. 2013. Using artificial illumination to survey nocturnal reef fish. Fisheries Research 146:41–50.

Kellner, K. 2021. ubms: Bayesian Models for Data from Unmarked Animals using "Stan."

Osgood, G. J., M. E. McCord, and J. K. Baum. 2019. Using baited remote underwater videos (BRUVs) to characterize chondrichthyan communities in a global biodiversity hotspot. PLOS ONE 14:e0225859.

Ream, C., and R. Ream. 1966. The Influence of Sampling Methods on the Estimation of Population Structure in Painted Turtles. The American Midland Naturalist 75:325–338.

Santori, C., R.-J. Spencer, M. B. Thompson, C. M. Whittington, T. H. Burd, S. B. Currie, T. J. Finter, and J. U. Van Dyke. 2020. Scavenging by threatened turtles regulates freshwater ecosystem health during fish kills. Scientific Reports 10:14383.

Schmid, K., and T. Giarrizzo. 2019. More than Fish – The Potential of Baited Remote Underwater Video to Assess Freshwater Herpetofauna and Dolphins. Proceedings of the Academy of Natural Sciences of Philadelphia 166:1–7.

Schmid, K., J. A. Reis-Filho, E. Harvey, and T. Giarrizzo. 2017. Baited remote underwater video as a promising nondestructive tool to assess fish assemblages in clearwater Amazonian rivers: Testing the effect of bait and habitat type. Hydrobiologia 784:93–109.

Singh, K. 2018. Ecology of the Macquarie turtle (Emydura macquarii macquarii) downstream of a large hypolimnetic-releasing impoundment in Australia's southern Murray-Darling Basin. Doctor of Philosophy, Charles Sturt University.

Spencer, R.-J. 2002. Growth patterns of two widely distributed freshwater turtles and a comparison of common methods used to estimate age. Australian Journal of Zoology 50:477.

Stobart, B., D. Díaz, F. Álvarez, C. Alonso, S. Mallol, and R. Goñi. 2015. Performance of Baited Underwater Video: Does It Underestimate Abundance at High Population Densities? PLOS ONE 10:e0127559.

Vehtari, A., J. Gabry, M. Magnusson, Y. Yao, P. Bürkner, T. Paananen, and A. Gelman. 2020. loo: Efficient leave-one-out cross-validation and WAIC for Bayesian models.

Vehtari, A., A. Gelman, and J. Gabry. 2017. Practical Bayesian model evaluation using leave-one-out cross-validation and WAIC. Statistics and Computing 27:1413–1432.

Whitmarsh, S. K., P. G. Fairweather, and C. Huveneers. 2017. What is Big BRUVver up to? Methods and uses of baited underwater video. Reviews in Fish Biology and Fisheries 27:53–73.

Appendix A – Additional information

BRUV set up and calibration

We used 4 stereo camera frames using steel, PVC piping and camera housings supplied by SeaGIS (www.seagis.com.au). The frames each hold 2 cameras (Sony FDR-X3000) in waterproof casings, allowing for stereo measurements of lengths, and a mesh bait bag that draws turtles close to the camera.

Each BRUV was calibrated in freshwater using a 500x500x300 millimetre calibration cube (SeaGIS). The recorded calibration imagery was processed using the CAL software package (version 2.00; SeaGIS).

BRUV deployment

To increase the likelihood of recording *M. bellii*, sites were selected where the species is known to occur (as recorded on bionet.nsw.gov.au). At each site, 4 BRUVs were dropped randomly at least 100 metres apart at a range of depths and pool microhabitat types (riparian overhang, sedge, silt, sand, cobble, boulder, snag or weed).

BRUVs were retrieved after approximately 60 minutes. At each site, water turbidity, temperature, electrical conductivity, pH, and dissolved oxygen content (% and mg) were recorded using a Hanna multiparameter water quality meter (HI-9829-13042). The depth and microhabitat at each drop were also recorded.

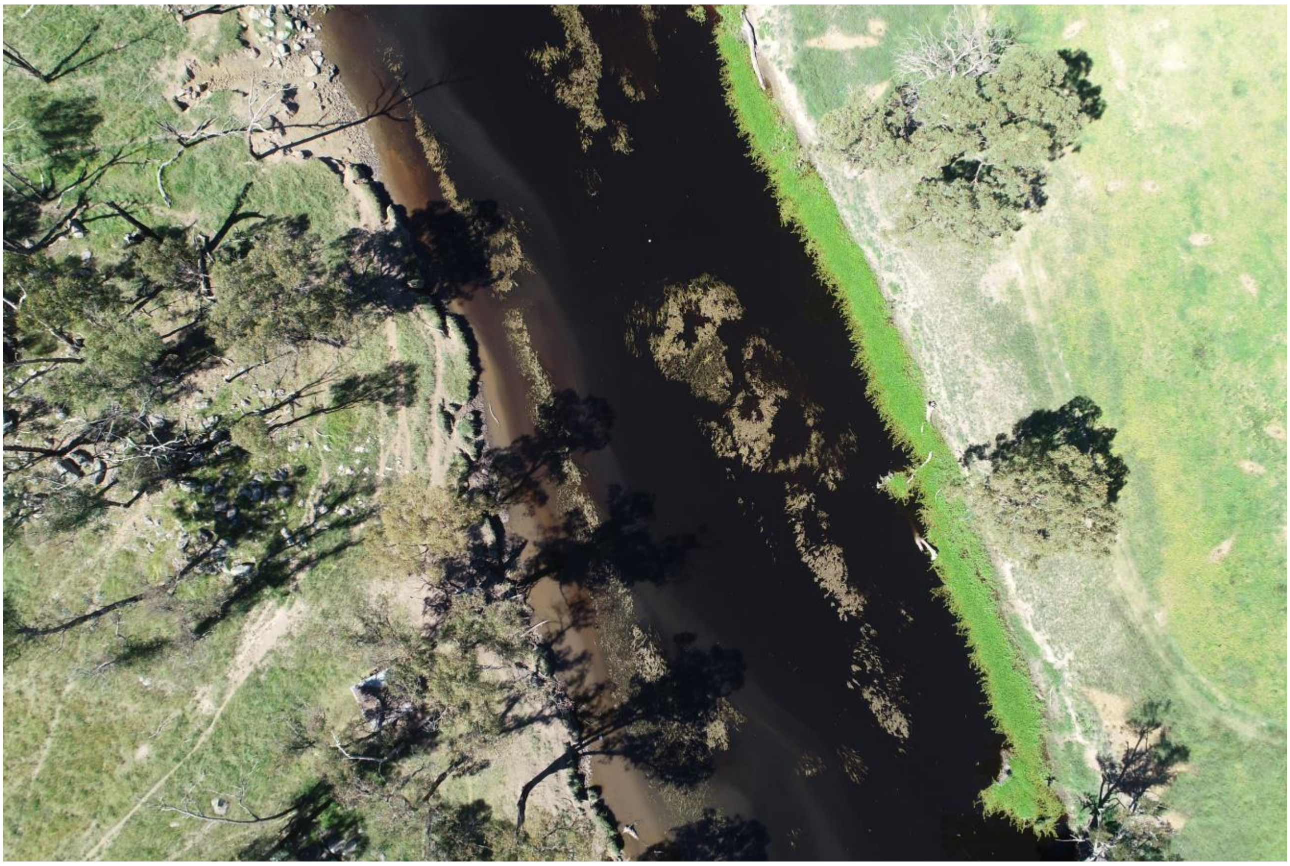

Figure A 1. Aerial image of the Severn River site taken using a Phantom 4 drone

Video processing

We processed the footage using EventMeasure software (SeaGIS). For each sample, the footage from each of the 2 cameras was loaded into EventMeasure and the timing synchronised. Samples were standardised to 60 minutes of footage from the time at which the BRUV landed (for some samples, less than 60 minutes of footage was available where, for example, the camera battery ran out).

For each sample, we recorded the time of first appearance by a species, the maximum number (MaxN) of individuals (within a species and in total) visible across both cameras at any one time, the time of MaxN (for individual species only) and species diversity.

MaxN is a commonly used good measure of species' relative abundance in BRUV analyses because it avoids double-counting (Osgood et al. 2019). MaxN does not reflect the total number of individuals that may have visited the BRUV at different times during its deployment.

Table A 1. Site details, sampling time and the number of samples collected for this study

Site	Location	Samples (by time period)	Samples
Cobrabald River (Cobrabald)	151.47◦E, 31.106◦S	4 x morning 4 x midday 4 x afternoon	12
Deepwater River (Deepwater)	151.84◦E, 29.443◦S	4 x morning 4 x midday	8
Roumalla Creek (Roumalla)	151.341◦E, 30.622◦S	4 x morning 3 x midday 4 x afternoon	11
Severn River (Severn)	151.77◦E, 29.453◦S	4 x midday 4 x afternoon	8
Gwydir River at Yarrowyck (Yarrowyck)	151.359◦E, 30.466◦S	4 x early 4 x midday 4 x afternoon	12
Total	NA	NA	**51**

Each BRUV held 2 simultaneously recording cameras to allow for stereo measurement of turtle carapace lengths. We had intended to use these length measurements to identify individual turtles and calculate the total number of unique individuals as a more accurate measure of abundance. However, due to poor visibility within rivers and issues with the proximity of the bait to the cameras, we were unable to obtain length measurements for all individuals.

Data analyses

We used several relative abundance indices in this study including MaxN, TotalN and turtles per trap-hour. A range of qualitative and quantitative analyses were undertaken using these indices. All analysis were done using R Studio and Microsoft Excel

Comparing BRUVs and cathedral traps

The number of turtles per trap-hour and the MaxN were used as a relative abundance index to compare between cathedral traps and BRUVs. They were calculated for the BRUV and cathedral trap data using the following formula:

$\text{MaxN}^{\text{BRUV}}$ = The most turtles (by species) visible across both cameras at any one time

$\text{Turtles per trap-hour}^{\text{CATHEDRAL}}$ = Total abundance ÷ (10 cathedral traps x 12 h)

We used a 2-way analysis of variance to test whether the relative abundance differed by species and BRUV sampling time. We used summary statistics and graphical comparisons to compare relative abundance results for BRUV and cathedral trap methods.

Modelling turtle populations using BRUV data

We used the Unmarked Bayesian Models with Stan (ubms) package (Kellner 2021) to fit models for predicting turtle occurrence and abundance. The TotalN BRUV data for each species was used for the model. Covariates included site turbidity, sample depth and time of day for each sample.

Several models were generated with a combination of each covariate (Table A 2, Table A 3 and Table A 4). Models for each species were compared using the leave-one-out-validation (LOO) (Vehtari et al. 2017) in the loo package (Vehtari et al. 2020) . Based on this cross-validation, the expected predictive accuracy (elpd) for each model was calculated. Larger expected predictive accuracies reflect the best model performance.

The difference between the model and the top performing model (elpd_diff) and the standard error of the difference (se_diff) was also used to identify which model performed best. The best model will have an elpd_diff value several times larger than the se_diff value.

Table A 2. Unmarked Bayesian Models with Stan (ubms) output for Macquarie River turtles

Model covariates	Expected predictive accuracy (elpd)	Nparam	Expected predictive accuracy difference (elpd_diff)	Standard error difference
Time + turbidity + depth	-6.216	1.181	0	0
Depth	-7.074	1.278	-0.858	0.86
Turbidity	-28.012	10.977	-21.796	10.372
Time	-29.209	9.347	-22.993	9.549
Null	-35.538	10.717	-29.322	14.421

Table A 3. Unmarked Bayesian Models with Stan (ubms) output for Bell's turtles

Model covariates	Expected predictive accuracy (elpd)	Nparam	Expected predictive accuracy difference (elpd_diff)	Standard error difference
Time + turbidity + depth	-17.982	1.691	0	0
Depth	-18.697	2.659	-0.715	1.207
Turbidity	-20.211	1.684	-2.229	1.421
Time	-21.025	3.066	-3.043	1.755
Null	-21.638	2.891	-3.656	0.824

Table A 4. Unmarked Bayesian Models with Stan (ubms) output for Eastern long-necked turtles

Model covariates	Expected predictive accuracy (elpd)	Nparam	Expected predictive accuracy difference (elpd_diff)	Standard error difference
Time + turbidity + depth	-6.542	1.47	0	0
Depth	-29.824	4.996	-23.281	12.623
Turbidity	-29.951	3.174	-23.408	9.908
Time	-31.13	4.464	-24.588	9.682
Null	-31.679	4.832	-25.137	10.79