Title: Development of a Castable, GPS enabled, Miniaturized Predation Event Recorder (mPER) to Quantify Predation of Juvenile Fishes

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Abstract:

Over the past decade, predation-event recorders (PERs) have become an effective tool to estimate relative predation rates of juvenile Chinook salmon in California's Central Valley. However, due to their design, PERs have primarily been limited to studying predation over relatively large spatial scales (up to several hundred meters or more). Due to this limitation, we designed a simple yet effective, castable, GPS enabled miniaturized predation-event recorder (mPER) based on an Arduino platform that can be adapted to meet individual applications. We tested our mPER by evaluating predation around a small-scale water diversion in the Sacramento-San Joaquin Delta. We modeled the relationship between predation risk and time to sunset as well as distance to diversion with a Cox proportional hazards model, a time-to-event model that accounts for censored data. The results of this proof-of-concept analysis indicated that for each elapsed minute, predation risk decreased by a factor of 0.97, as sunset was approached and passed. Similarly, each meter increase in distance from the diversion decreased the predation risk by a factor of 0.86. The mean relative predation rate in our study area was 24%. Our mPERs proved to be an inexpensive, effective, and reliable tool to quantify predation, in a repeatable manner, around targeted locations of interest. We have included the design, material list, Arduino programming code, and Cox proportional hazard analysis code for others to easily design, use, and analyze the resulting data from our mPER design (supplementary information available from the Open Science Framework https://osf.io/ysm2p/).

Keywords: mPER, PER, Arduino, Chinook salmon, predation, Sacramento-San Joaquin Delta

1. Introduction

Predator-prey interactions are of key importance to understanding ecological dynamics (Krebs et al., 2001). However, observing and quantifying predation events *in situ* in the aquatic environment is rare and requires large observational sample sizes often over extended periods of time (Hunsicke et al., 2011). For this reason, most research into predator-prey interactions amongst fishes have been observed in either highly modified habitats or the laboratory, allowing researchers to control the movement, timing and interaction of both predator and prey (Sabal et al., 2020; Zeug et al. 2020). Alternatively, fixed tethering experiments have been widely used to quantify relative predation rates. However, these experiments are plagued by the fact that mobile prey are fixed in place, which may artificially increase mortality and alter prey behavior, and the spatial extent of sampling is limited (Peterson and Black, 1994).

Over the past decade Predation Event Recorders (PERs) have overcome some of the limitations associated with fixed tethering. PERs (as described in detail by Demetras et al., 2016) are passive, floating GPS enabled platforms which can be baited with a variety of different prey species and have been employed to evaluate relative risk of predation and observe associated predation events. Although prey are still tethered, drifting PERs are an improvement over fixed tethering designs, because drifting tethers better mimic free-swimming prey and heterogeneous habitats across variable spatial scales can be sampled. PERs are an effective tool used to estimate relative predation rates of juvenile Chinook salmon (*Oncorhynchus tshawytscha*) in the Sacramento River (Cunningham, 2020), San Joaquin River (Demetras et al., 2016; Michel et al. 2020a) and in the Sacramento-San Joaquin Delta (Michel et al., 2020b; Nelson et al., 2021). PERs have been utilized to investigate the effects of local features on predation rates (Cunningham 2020; Nelson et al., 2021), evaluate the success of predator removal efforts (Michel et al., 2020a) and estimate predation risk on a landscape scale (Michel et al., 2020b).

While effective at sampling on a relatively large spatial scale (up to 1 km or more), traditional PERs are large (750 mm length x 44 mm diameter), heavy (3 kg) and require a minimum of two people and at least one boat to be effectively deployed. Their autonomous nature, once released, relies on local water currents and hydrodynamic processes to carry them throughout a study site and may make it difficult to consistently target specific features or habitats. In addition, the majority of the PER is situated below the waterline when sampling, precluding their use in habitats shallower than 75 cm.

These limitations led us to redesign the traditional PERs to meet three specific goals: they must be 1) easily deployable by a single individual, 2) able to accurately and repeatedly sample a specific area, and 3) able to effectively sample a range of shallow water habitats less than 1m in depth. To this end we designed, fabricated, and tested a miniaturized predation event recorder (mPER) that reliably identified the location of individual predation events. Most importantly our mPER design was easily baited, deployed and retrieved by a single person from either the bank or a boat. We successfully tested our mPER design around an agricultural pump station in the Sacramento-San Joaquin Delta and were able to estimate mean predation rate, model the relationship between predation risk and time to sunset as well as distance to diversion with a Cox proportional hazards model and created heat maps of predation within our study area.

2. Methods

2.1 Internal Electronics and Hardware

The mPER used the open-source TinyDuino Platform for its internal electronics and programming, which is a miniaturization of the popular open-source Arduino platform (https://tinycircuits.com/pages/tinyduino-overview). As such, the hardware and software we present here can be converted to their Arduino counterparts if space allows. In addition to the miniaturized hardware, the TinyDuino processors can be easily stacked with multiple TinyShields using a built-in 32 pin connector without soldering. This ability allowed us to create a compact hardware stack starting with the TinyZero processor on bottom, followed by the microSD, protoboard, and GPS TinyShields (Fig. 1, Table 1). We chose the TinyZero over the TinyDuino given the greater memory capacity of this board and used a 16GB SD card (FAT32 formatting) for data storage. On the protoboard, we soldered the positive lead of a small red LED light to pin port 8 and the negative lead to a ground port. We also soldered a reed switch to the protoboard using pin 2 and an additional ground port. To hold this stack together, we used the TinyDuino mounting hardware kit, consisting of four small bolts, nuts, and spacers that fit into pre-drilled holes on the processor and shields. We used cyanoacrylate glue to affix the reed switch to four, 13mm diameter, stacked steel washers mounted internally in the lower external casing. These steel washers provide the magnetic attraction for the outer magnet (more below). We powered the mPER with a 3.7v 500 mAh rechargeable lithium battery, which provided roughly 10 hours of maximum operation time. A fully decharged unit can be recharged in less than 10 hours using a standard microUSB charging cable. Finally, we secured all electronics with anti-static foam and electrical tape inside the external casing.

2.2 External Casing, Rigging, and deployment:

The external mPER casing consisted of two parts, a female threaded upper housing and a matching male threaded lower housing (Fig. 2). The upper housing was 3D printed using stereolithography (SLA) Somos® Watershed XC 11122 resin (for .stl file see supplementary information available from the Open Science Framework https://osf.io/ysm2p/). This resin allows for a clear, transparent finish that is water and UV resistant with no need for an external coating. The transparent finish of the upper housing allows for viewing of a small red LED light, activated upon predation. The lower housing was 3D printed with multi jet fusion (MJF) nylon (for .stl file see supplementary information available from the Open Science Framework https://osf.io/ysm2p/). MJF nylon is affordable, durable and requires minimal post production finishing. However, MJF nylon is hygroscopic and will readily absorb water if not properly sealed. To accomplish this the lower housing was spray painted a dark green inside and out then sealed with multiple coats of clear polyurethane spray. MJF nylon was used to print the lower casing due to its reduced cost, quicker lead time, and increased availability. As 3D printing technology advances, more affordable hydrophilic compounds like those used for the top housing should become available. The bottom of the lower housing was printed with a 15 mm x 5 mm indentation (Fig. 2) designed to fit a circular magnet used to trigger an electronic reed switch when predation occurred.

To prevent water intrusion, a 47.6 mm inside diameter "Buna-N" style o-ring with a 2.4 mm square profile was seated between the upper and lower portions of the mPER and coated with a thin layer of silicone. In addition, PTFE tape was used to waterproof the housing threads. Approximately 4g of lead ballast, placed at the bottom of each mPER served to keep them upright while submerging all but the top 40mm of the upper casing.

We used an externally mounted, neodymium magnet (13 mm diameter x 6mm height), fit within the recessed indentation of the lower housing to activate the reed switch. The magnet was held in place through magnetic attraction to the internally mounted washers with a pull strength of approximately 80g. Forty pound test braided fishing line was glued in place through a small hole in the center of the magnet allowing the attachment of a small barrel swivel which serves to connect the magnet to the lower casing and to a baited fluorocarbon leader (Fig. 2). The fluorocarbon leader, used in trials, was approximately one meter in length with a 7g split shot approximately 30cm above a 5cm loop at the terminal end.

Live juvenile Chinook salmon from the Mokelumne River Fish Hatchery were attached to the mPER by threading the fluorocarbon leader through the mouth and out the operculum, after which the mainline was passed through the terminal loop to create a lasso. The fork length of juvenile Chinook salmon ranged from 55 mm to 75 mm with a mean FL of 66.6 mm and a standard deviation of 4.3 mm. mPERs were attached to a rod and reel using 40lbs braided fishing line. Typically, mPERs were cast no more than 10m but were deployed up to 20m when necessary. We tested the design and performance of our mPER in the field near a small agricultural pump station in the Sacramento-San Joaquin Delta. The red LED light was designed to indicate a predation event, and the clear top allowed the researcher to retrieve the mPER and re-bait it in an effort to increase deployments and minimize wasted study time after a predation event had occurred.

2.3 Programming, Data Reduction, and Processing

We wrote the mPER code (Supplemental Materials) in the Arduino integrated development environment and based it on open-source examples (GPS Tracker and Data Logger, MicroSD TinyShield) and our previous work (Lockridge et al. 2016). The code steps through the following sequence once the mPER is powered on. First, SD card communication is initialized and a new .CSV data file is created. The file is named with a user defined mPER identifier and a number indicating its place in the file sequence on the SD card. Next, the header row of the .CSV is created consisting of date and time (Date_Time), Latitude (Lat), Longitude (Long), and predation status (Pred) columns. Communication is then initialized with the GPS module and once a satellite lock is obtained, logging of position and predation data is initiated. If either of these steps fails, data logging will not begin. Correct startup can be monitored through the serial monitor prior to field deployment and can also be visually assessed in the field by ensuring the red LED is illuminated when the magnet is pulled. A small green LED is also located on the processor board to indicate logging, but this can be difficult to see. After initiation, the current date and time (obtained from the GPS), mPER Latitude, Longitude, and predation status is recorded every second (user defined interval) within the respective CSV column. The predation status variable is controlled by the external magnet and reed switch, recording a 0 when the bait has not been predated (magnet still attached) or a 1 when predation occurs (magnet pulled). A 1 will be continuously recorded for the predation status variable every second until the magnet is replaced in its starting position. The red LED indicator is also controlled by the reed switch, illuminating when a predation event has occurred. Therefore, the precise location and time of predation events are recorded within the mPER .CSV file and it is indicated in real time to the researcher by the red LED.

Our current design records data continuously once the GPS is initialized, whether or not it is deployed on the water. We have not yet incorporated a way for unique mPER deployment event start and end times to be recorded internally. GPS coordinates could be used to infer when an mPER was deployed based on position, but we found it simpler to use an external log of deployment start and end times. We used various ‘time stamp’ phone apps to do this to both 1) ensure we have exact cellular network time so as to synchronize with GPS time in the mPER, and 2) enable simple and waterproof electronic data entry on researcher’s cell phones. We then imported deployment start and end times into R along with any associated deployment notes and the mPER .csv file. We developed code (Supplemental data) to filter data that occurred only during marked mPER deployments. In this code we also deleted deployments where the magnet was pulled on the first data point, which indicated it was pulled during the cast, and any deployments we deemed compromised during sampling (such as due to tangled fishing line). Finally, any rows after the initial predation event during a deployment were deleted.

2.4. Data Analysis

We used a Cox proportional hazards model to assess time to predation and relative predation risk (Nelson et al., 2021). These models are time-to-event models that are commonly used in clinical studies in the medical field, and assess the influence of factors and covariates on the instantaneous probability of an event (here, predation) occurring (Cox, 1972). To assess whether the relative predation risk of juvenile Chinook salmon was related to time until sunset, a significant driver of predation in previous studies (Michel et al., 2020; Nelson et al., 2021), and distance to a nearby water diversion, a hypothesized predation driver, we implemented a Cox proportional hazards model. We fit this model using the ‘coxph’ function in the ‘survival’ package in R and checked proportional hazards assumptions using the ‘cox.zph’ function (R core team, 2021; Therneau, 2015).

2.5. ARIS Deployment

A boat mounted ARIS sonar camera (Sound Metrics, Seattle, Washington USA) was used to visualize a portion of each deployment directly adjacent to the water diversion and to clearly observe the mPER underwater. The ARIS camera was aimed perpendicularly from the anchored boat in an attempt to capture underwater footage of mPER deployments.

3. Results

We successfully made 25 test deployments of our mPER over a three hour period on the evening of May 13th, 2021 between the hours of 1700 and 2100 PDT. Deployment length ranged from a minimum of 11s to a maximum of 647s with a mean deployment length of 179s (+/-160 SD). Of the 25 total deployments, 6 resulted in a predation event for a relative predation rate of 24%. Throughout the test deployments the mPER was easily baited, deployed, and metadata was recorded, all by a single person. The external casing and electronics proved to be rugged and functioned as designed. We used the spatially explicit predation data produced by the mPER to produce accurate maps of mPER pathways with predation event locations as well as predation and effort heat maps of the study area (Fig. 3). Underwater ARIS footage clearly showed our mPER and attached bait, and was able to capture and visually confirm some of the observed predation events (Supplemental Material).

The cox proportional hazards model found that predation risk decreased as time-to-sunset decreased and distance to diversion increased, although only time-to-sunset was significant at a p-value less than 0.05. The coefficient for time-to-sunset was -0.03 and distance to diversion was -0.15. The exponentiated coefficient for time to sunset was 0.97 and 0.86 for distance to diversion (Table 2). Exponentiated coefficients are interpretable as multiplicative effects on the hazard (here, predation risk). For example, by holding the distance to the diversion constant, every minute that passed from the start of our trial and progressed towards sunset and beyond, decreased the predation risk by a factor of 0.97. Similarly, holding time-to-sunset constant, each meter increase in distance from the diversion decreased the predation risk by a factor of 0.86 (Fig. 4).

4. Discussion

Predation in the aquatic environment is notoriously difficult to measure and observe *in situ*. However, it can provide a wealth of information about environmental conditions that influence predation that are often lacking in lab-based experiments (Schneider et al., 2021). Predation and its potential impacts on juvenile Chinook salmon populations in California's Sacramento-San Joaquin Delta has been a focus of study for the past decade (Demetras et al. 2016; Michel et al., 2020a; Michel et al. 2020b; Nelson et al., 2021). These studies primarily employed the use of traditional PERs in study sites of several hundred meters to kilometers in reach length (Michel et al., 2020b; Nelson et al. 2021). While effective at measuring rates of relative predation over large distances, traditional PERs can be difficult to employ if investigating the effects of localized features and their influence on predation. Due to their free floating design, they can be difficult to deploy with repeated accuracy adjacent to designated features, and therefore, traditional PERs may be unable to collect sufficient information to accurately measure the localized effect such features can have on predation.

The ability to directly control an mPER's area of sampling, using a traditional fishing rod, allows the researcher to repeatedly target habitat features without the need to recover free floating PERs after they have adequately sampled the desired location. The mPER is simply reeled back in discretely and can be immediately re-baited or deployed. In our experience, recovering free-drifting PERs can be a time-consuming task that limits effective sampling time. In addition, if PERs are being deployed by boat, motor noise during positioning and retrieval may influence the behaviors of targeted fish species. Another benefit of castable mPERs is the ability to fish logistically difficult areas repeatedly, such that sufficient samples are gathered to generate statistically robust relationships. For example, sampling near navigation hazards, such as dams or large in-river structures with swift current, mPERs can be deployed from a safe distance, and cast directly into the presumed area of influence of the local habitat feature. Miniaturized PER location can also be adjusted after casting due to their leashed design, ensuring the mPER will drift in close proximity to the target feature. Miniaturized PERs may also be preferable over the much larger PERs when sampling in areas with high water clarity and with predators that may be overly timid while feeding. Finally, mPERs are not strictly limited to deployment by casting, they can also be deployed in a free-drifting manner, assuming that they can easily be re-sighted and recovered. When recovery proves challenging, integrating a general system for mobile communication (GSM) module with a subscriber identity module (SIM) card into the mPER design, should allow a live tracking feature, viewable on a smartphone, to be incorporated into the free drifting design (Woo, 2017).

While mPERs have many advantages over traditional PERs, some issues need to be considered. If used as a castable unit, the total effective deployment area is limited by the length of line available. In addition, care must be taken to ensure that the magnet does not get prematurely removed during the casting process. However, the built-in red LED, triggered when the magnet is pulled, does make it easy to quickly identify and remedy this situation. Similarly, attention and care needs to be taken not to injure the live tethered prey during the casting process. While mPERs are very effective at sampling a localized feature, when leashed to a fishing pole they are not appropriate for investigating predation over large distances or landscape scales where traditional PERs excel (Michel et al., 2020b). Ultimately, the researcher will need to assess if classic PERs or mPERs are appropriate for their research question.

At times, a combination of both platforms could be used, where mPERs allow for supplemental sampling alongside traditional free-floating PERs, so as to ensure sufficient coverage near specific habitat features. Furthermore, the concurrent use of both mPERs and traditional PERs may allow for comparisons of relative predation rates between the two platforms. If done across habitats, this may allow the researcher to customize the use of either mPERs or traditional PERs to specific habitats of interest and make meaningful estimates of relative predation rates across a range environmental conditions (e.g. turbidity, flow etc.) and between species (e.g. centrarchids, salmonids etc).

One particular criticism of PERs in general has been their ability to elucidate whether the measured relative predation rates are equally proportional to actual predation rates, especially across differing habitat types. Whenever possible, we advise two steps to avoid this potential issue. First, during the pilot phase of a study, researchers should visually observe the live prey underwater either with cameras or snorkeling alongside to ensure it is effectively sampling various habitats and conditions similarly. Second, if possible, researchers should also employ independent methods for estimating predation or survival to ensure concurrence with conclusions drawn from PER data. For example, researchers may be able to leverage survival data from acoustic telemetry studies, to investigate areas of low survival with mPER data. Using a suite of approaches including mPERs, should provide a better estimate of predation when compared to inferences drawn from single methods alone. .

The ability to customize the size of the 3D printed external casing allows for the addition of other sensors to measure environmental factors that may affect predation. For example, the addition of an internally mounted light sensor could measure light levels both temporally and spatially in an effort to understand its effect on predation. Lockridge et al. (2016) developed a low cost sonde, for coastal applications, that operated in a very similar fashion to our mPER and could easily be incorporated into our framework to add additional water quality information that may affect predation. Furthermore, we did not incorporate a way to determine deployment time into our design and relied on external timestamps for this information. It is possible to add a toggle or push button switch to indicate if a deployment is occurring, but this may add another place for water intrusion into the unit. One remedy to this potential intrusion is to add an additional reed switch to be triggered each time a deployment occurs. However, care needs to be taken to ensure this switch is not impacted by the predation trigger. These examples highlight the adaptability of open-source code, hardware, and 3D printing and we encourage future investigators to be creative in their designs expanding on the mPER framework we present here.

Our finding of a mean relative predation rate of 24% around the targeted water diversion is higher than the mean relative predation rate reported by Demetras et al. (2016) in the San Joaquin River using traditional, freely drifting PERs. Due to the limited spatial and temporal sampling of this “proof of concept” study, overall relative predation rates should be interpreted with caution, not be taken out of context or extrapolated outside of the immediate study area. This relatively high level of relative predation allowed us to assess the overall functionality of our mPER design and demonstrate the usage of a Cox proportional hazards model with the resulting data. In addition, we were able to produce easily interpretable heat maps of predation in our study area that aid in understanding those results.

Our limited deployments in this study may leave some question to the physical robustness of our mPER design over extended periods of sampling. However, we have successfully used our design extensively in an attempt to assess variable predation drivers in a swift flowing river. We deployed mPERs 1471 times over five consecutive weeks to investigate the impact of artificial light emanating from The Sundial Bridge in Redding, CA on salmonid fry (Nelson et al., 2022). However, extremely low levels of predation (n=4), due to the low piscivorous nature of Rainbow trout (*Oncorhynchus mykiss*) in the study area resulted in an ineffective sample size that did not allow for meaningful statistical analyses of relative predation rates (Nelson et al., 2022). Although only 4 predation events occurred in Nelson et al. (2022), the mPERs functioned smoothly throughout the entirety of the study. Furthermore, the data presented here is part of a larger study that leveraged traditional PERs and mPERs to assess water diversion impacts on salmonid predation across varying spatial scales in tidal freshwater. In this larger diversion study mPERs were deployed 530 times over 29 days and received 60 predation events (unpublished data).

The use of mPERs is also not restricted to salmonids or these environments. For example, predation mortality is one factor that may contribute to diminished River Herring (*Alosa sp.*) populations along the east coast (Hare et al., 2021) and drivers of River Herring predation (e.g. submerged aquatic vegetation and barriers to migrations) could be elucidated with this method. In lakes, coarse woody habitat and aquatic macrophytes provide refuge from predation (Sass et al. 2006) and mPERs could be deployed to determine a continuous predation risk gradient along the littoral pelagic transition. Low salinity is also a likely predation refuge for juvenile estuarine nekton (Manderson et al., 2006; Posey et al. 2005) and mPERs could be deployed in both low and high salinity estuarine environments to further test this hypothesis in conjunction with other habitat features. These examples and our work presented here exemplify how mPERs could be easily adapted to nearshore marine, estuarine, lacustrine, or fluvial environments elucidating a suite of predator-prey interactions across a wide range of habitats and species.

5. Conclusion

Our mPER design is a direct customization of the traditional PER that enhances sampling efficacy, especially in areas of limited accessibility (Demetras et al., 2016). Their small size, ease of deployment, and ability to sample targeted environments allows them to be used in habitats where traditional free floating PERs may not work. The much smaller GPS unit and Arduino based data recorder, mounted internally, result in a simple, robust, waterproof, and rugged platform requiring less maintenance and troubleshooting than traditional PERs. Our design provides a cheap ($282/unit) and simple device to measure predation that can easily be deployed in a variety of aquatic environments, using a variety of baits. Although we designed this framework for mPERs, the same coding system could be adapted across platforms that utilize a predation detecting reed switch to investigate *in situ* predation of aquatic organisms across many applications.

CRediT authorship contribution statement

Nicholas J. Demetras: Conceptualization, Methodology - mPER housing design and construction, Field deployment, Investigation, Writing – original draft, Writing - review and editing. **T. Reid Nelson:** Conceptualization, Methodology - mPER Arduino design and programming, Field deployment, Investigation, Writing – review and editing. **Brendan M. Lehman** – Field deployment, Investigation. **Cyril J. Michel:** Project administration, Field Deployment, Investigation, Formal analysis, Writing – review and editing.

Declaration of Competing Interests

The authors declare that they have no conflicts of interest.

Acknowledgements

The authors would like to thank Paul Carvalho, Eric Danner and two anonymous reviewers for critical and insightful comments on the original version of the manuscript. Funding was provided by the Central Valley Project Improvement Act Anadromous Fisheries Restoration Program administered by the U.S. Bureau of Reclamation (grant agreement R18AP00136). The funders had no role in study design, data collection analysis and the decision to publish. Fish handling was conducted under University of California, Santa Cruz IACUC #KIERJ1604. Material and logistical support was provided by the National Marine Fisheries Service Southwest Fisheries Science Center. Reference to trade names or parts suppliers/websites does not constitute endorsement by the US Government.

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Figures:

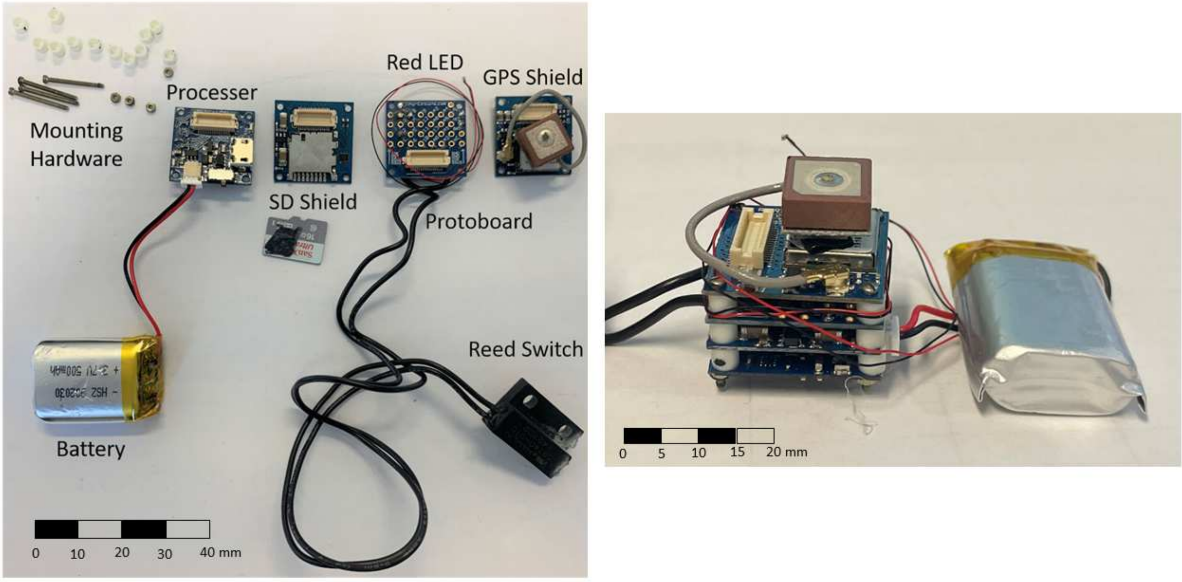

Fig.1. Internal Electronics and Hardware.

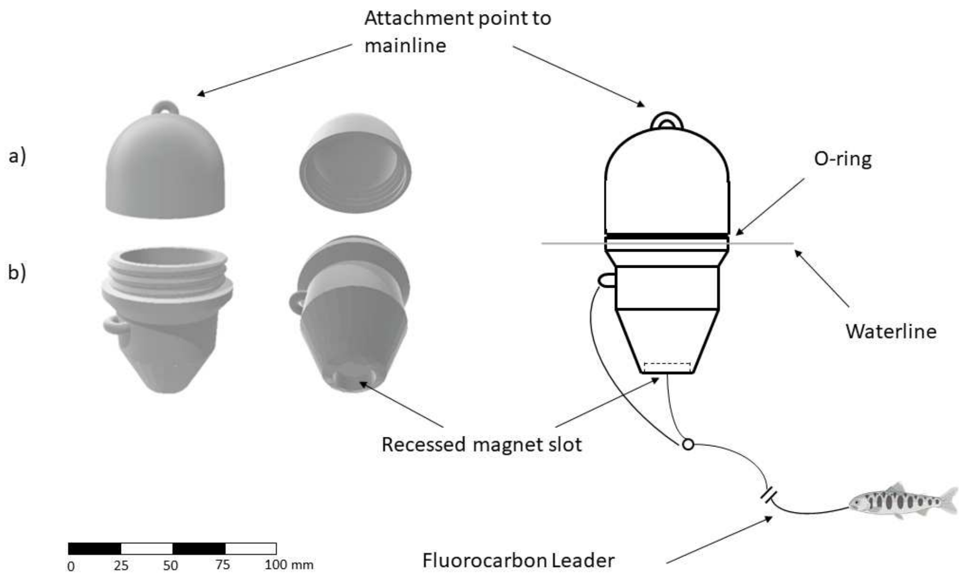

Fig. 2. Three dimensional view of a) upper, b) lower external mPER casings, and c) schematic of mPER with attached salmon smolt as bait.

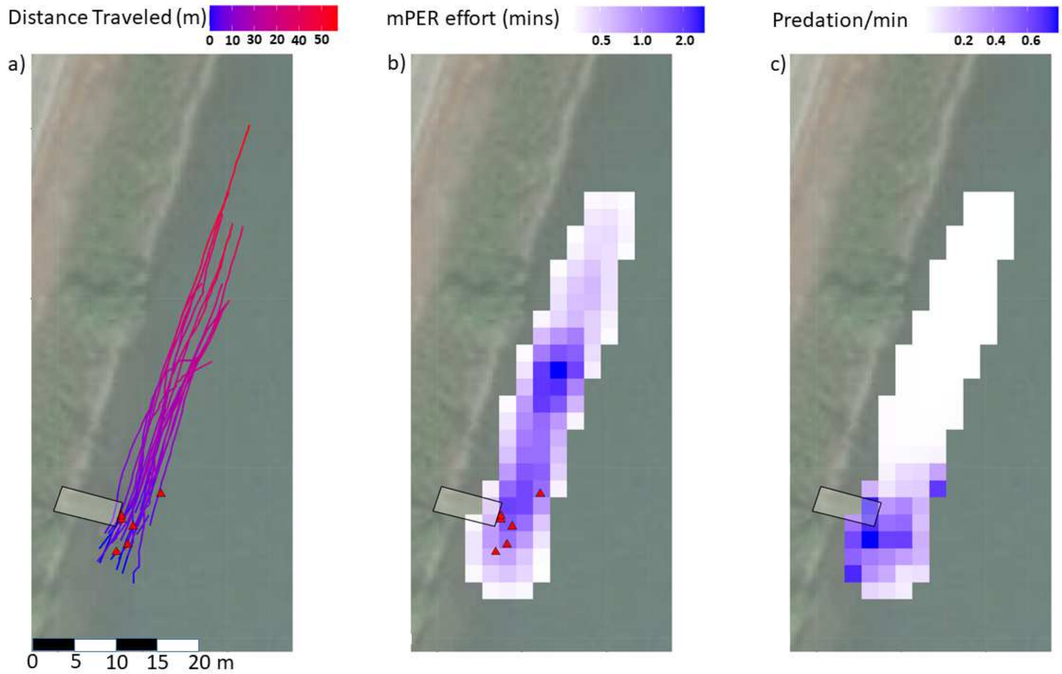

Fig. 3. mPER tracks and predation associated heat maps with overlaid predation locations (red triangles). Diversion location is represented by a black outlined polygon and individual predation locations by a red triangle. Panel a) mPER tracks with distance traveled (m) with locations of individual predation events. Panel b) Heat map of mPER effort (mins) overlaid with individual predation event locations. Panel c) Heat map of predation/min within our study site.

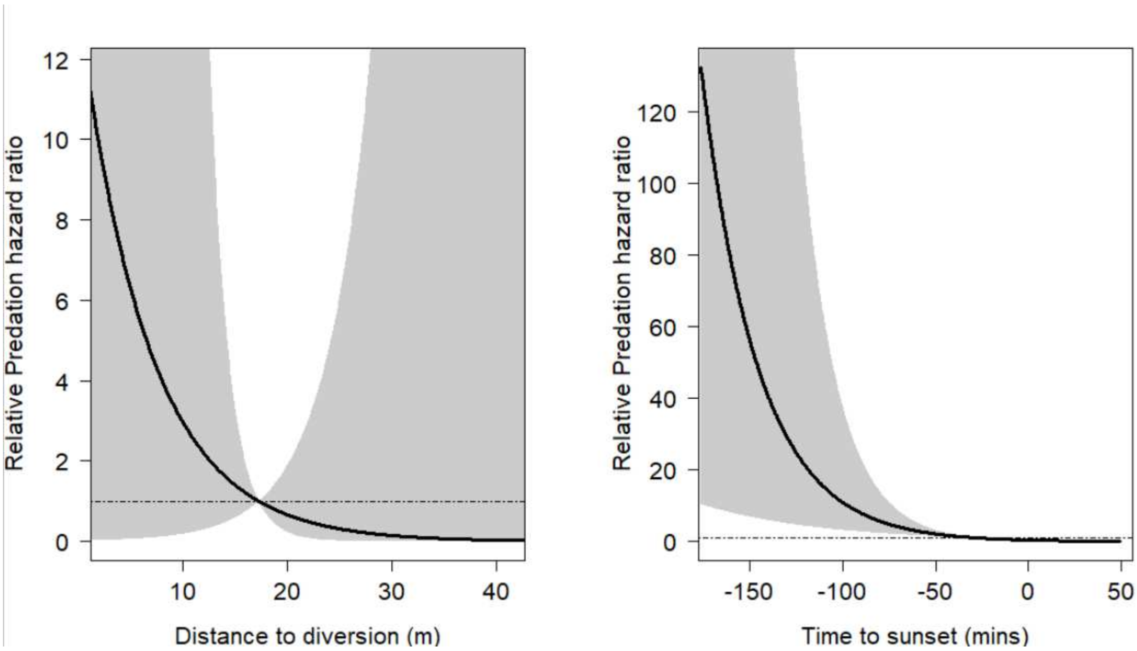

Fig. 4. Predicted relative predation risk in relation to a) distance to diversion and b) time to sunset. Predictions (solid black line) above the horizontal dashed line (risk = 1) indicate increased relative predation risk and below the dashed line represent decreased risk with 95% confidence intervals in gray. Where the solid black line crosses the dashed line is the mean observation of each variable within each model.

Tables:

Table 1. Individual and total components cost for mPER construction

Tiny Circuits parts	**Price**	Part No.
TinyZero Processor board accelerometer not present	$19.95	ASM2021-R

TinyShield Proto Board w/ connector present	$3.95	ASD2009-R-T
GPS TinyShield	$59.95	ASD2501-R
MicroSD TinyShield	$14.95	ASD2201-R
TinyDuino Mounting Hardware kit	$3.95	ASH1002
Lithium Ion Polymer Battery 3.7V 500MAH	$6.95	ASR00035
Other Parts (internal)		
Reed Switch (single throw) Hamlin 59140-010	$3.44	59140-010
EDGELEC Prewired 0402 Red SMD MircoLED	$0.45	402
SanDisk 16GB microSD card	$12.49	
Electrical tape	$7.63	
Antistatic Foam	$7.21	
Solder	$7.39	
(4) 13 mm Steel washers	$0.76	
External Casing, Rigging, and Maganet		
Neodymium magnet Model R824 Ring Magnet	$1.64	R824
150 yd 40 lbs braided fishing line for magnet tether	$23.99	
SS 7mm 10 lbs micro swivels	$6.99	
3D - Printed upper housing	$62.50	
3D - Printed lower housing	$18.45	
Square Profile Buna O- Ring	$9.27	4061T18
PTFE tape	$2.39	
Silicone Grease	$7.86	
Total Cost	$282.16	

Table 2. Summary of Cox proportional hazards model.

	coef	exp(coef)	se(coef)	z	Pr(>|z|)
Distance to diversion (m)	-0.15	0.86	0.3	-0.5	0.62
Time to sunset	-0.03	0.97	0.01	-2.46	0.01