# Visible implant elastomer (VIE) success in early larval stages of a tropical amphibian species

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## Abstract

Animals are often difficult to distinguish at an individual level, but being able to identify individuals can be crucial in ecological or behavioral studies. In response to this challenge, biologists have developed a range of marking (tattoos, brands, toe-clips) and tagging (PIT, VIA, VIE) methods to identify individuals and cohorts. Animals with complex life cycles are notoriously hard to mark because of the distortion or loss of the tag across metamorphosis. In frogs, few studies have attempted larval tagging and none have been conducted on a tropical species. Here, we present the first successful account of VIE tagging in early larval stages (Gosner stage 25) of the dyeing poison frog (*Dendrobates tinctorius*) coupled with a novel anaesthetic (2-PHE) application for tadpoles that does not require buffering. Mean weight of individuals at time of tagging was 0.12g, which is the smallest and developmentally youngest anuran larvae tagged to date. We report 81% tag detection over the first month of development, as well as the persistence of tags across metamorphosis in this species. Cumulative tag retention versus tag observation differed by approximately 15% across larval development demonstrating that "lost" tags can be found later in development. Tagging had no effect on tadpole growth rate or survival. Successful application of VIE tags on *D. tinctorius* tadpoles introduces a new method that can be applied to better understand early life development and dispersal in various tropical species.

## Introduction

Distinguishing individuals within a population is often key in deciphering animal behavior. Animal identification has applications in understanding parental care (Ménard et al., 2001), migration dynamics (Matthews et al., 2011) and social hierarchies (Holekamp et al., 1997). Studies across the animal kingdom have developed methods that vary both in invasiveness and success (guppies: Croft et al., 2003; dolphins: Defan et al., 1990; bears: Diefenbach & Alt, 1998; salamanders: Osbourn et al., 2011) to allow researchers to differentiate between individuals within groups. If visual differentiation is not an obvious option, physical manipulation (e.g. toe clips, tattoos; Perret & Joly, 2002; Phillott et al., 2007) and tagging (i.e. passive integrated transponder (PIT), visible implant alphanumeric (VIA), visible implant elastomer (VIE); Phillott et al., 2007; Donnelly et al., 1994) have been the most commonly used methods implemented in mark-recapture studies.

Differentiating individuals is important when there is a lot of intrapopulation variation in behavior, and is becoming especially relevant as we begin to see individuals adapt to new challenges onset by the effects of global warming, habitat fragmentation, and human interactions. However, long-term marker-based studies have not often been applied to animals with complex life cycles, as the physical transformations induced with metamorphosis and growth generally entail the loss or distortion of the mark. In anurans, there have been a range of successful tagging methods both in adult and larval stages, but the diversity of larval tagging studies has been limited to common temperate species (e.g., Campbell Grant, 2008; Courtois et al., 2013), and very few studies have been able to create a methodology that spans the animal's entire life cycle (Bailey, 2004; Bainbridge et al., 2015; Caballero-Gini et al., 2019; Campbell Grant, 2008; McHarry et al., 2018). The current reported success rate of tags could be inaccurate for species outside of temperate regions. Tadpoles, especially those from neotropical regions, are known to be tremendously plastic with respect to morphology (Touchon & Warkentin, 2008), time-to-metamorphosis (Rudolf & Rödel, 2007), and even pigmentation (McIntyre et al., 2004), all of which could affect tag success.

Understanding the dispersion dynamics and survival of anurans from aquatic to terrestrial habitats makes developmentally early larval tagging especially interesting. For example, many species of poison frogs have parental care where recently hatched tadpoles are

67  transported from terrestrial sites to arboreal pools (Pašukonis et al., 2019; Ringler et al.,

68  2013; Schulte & Mayer, 2017; Summers & Tumulty, 2013). Tadpole tagging could provide a

69  quick and reliable method of following individuals across development, understanding

70  relatedness within pools, and observing tadpole behavior and parental care in the field. Here,

71  we use a novel anesthetic procedure for tadpoles followed by a VIE tag application on dyeing

72  poison frog (*Dendrobates tinctorius*) larvae that is then monitored throughout development.

73

74  Larval anuran tagging has been limited with respect to both developmental stage and weight.

75  Most of the larval tagging to date has been done beyond the point of the onset of hind leg

76  development (Andis, 2018(Gosner stage 30); Bainbridge et al., 2015 (Gosner stage 36-38)).

77  At this point *D. tinctorius* tadpoles are typically at least a month old, meaning they have

78  already been transported by their fathers and have long since been subject to both predation

79  risk and aggression by conspecifics (CF personal observation; Rojas, 2014, 2015; Rojas &

80  Pašukonis, 2019). Therefore, in order to obtain more valuable life history information, tags

81  need to be applied earlier in development.

82

83  To our knowledge, the developmentally earliest tagging study applied VIA/VIE tags around

84  Gosner stage 25 (Courtois et al., 2013; Gosner 1960), but its application was limited to large

85  temperate tadpoles (average weight around 1.5g) that could be manipulated in the field

86  without anesthesia. In this study we use 2-phenoxyethanol, an anesthetic that does not need to

87  be buffered and can be stored at room temperature (Acme-Hardestry, 2013; National Center

88  for Biotechnology, 2020), making it field appropriate, and applied VIE tags to the smallest

89  and developmentally earliest stages of larval anurans recorded to date. We follow growth rate

90  and tag success across development, and discuss potential field applications in order to better

91  understand the dispersion dynamics and behavior of protected frogs.

92

93  **Materials & Methods**

94

95  *Study organism* – We used tadpoles from a breeding laboratory population of *Dendrobates*

96  *tinctorius* kept at the University of Jyväskylä, Finland. Adult pairs are each housed in a 55L

97  terrarium that contains layered gravel, leaf-litter, moss substrate and is equipped with a

98  shelter, ramps, and live plants. Terraria are maintained at 26C (±2C) and are automatically

99  misted with reverse osmosis water four times a day, maintaining a humidity around 95% and

100  lit with a 12:12 photoperiod. Frogs are fed live *Drosophila* fruit flies coated in vitamin

101     supplements three times per week. Tadpoles are raised singly in 10 x 6.5 x 5 cm cups which

102     are filled with spring water, and fed *ad libitum* a diet of fish food (JBL NovoVert flakes)

103     three times a week. Adult and tadpole health and water levels are checked daily, and

104     experimental tadpoles were weighed and photographed weekly.

105

106     *Anesthesia*—Prior to tagging, tadpoles were anesthetized in a 14mL solution of a 1µl:1mL

107     ratio of 2-phenoxyethanol (2-PHE) to spring water. 2-phenoxyethanol is an oily liquid at

108     room temperature and does not need to be buffered for anesthetic purposes (Coyle et al.,

109     2004). The solution was reused multiple times for multiple tadpoles within a single day of

110     tagging; its effect did not deteriorate after multiple uses. Each day of tagging a new solution

111     was made. Tadpoles were placed in anesthetic solution until there was no muscular

112     contraction in response to agitation. This took approximately 3 minutes. The effect of

113     anesthesia on tadpoles lasted approximately 6 minutes; within 10 minutes individuals had

114     regained full muscular function. The effects of anesthesia were similar across developmental

115     stages. We had no deaths in response to our anesthesia procedure, which was applied to a

116     total of 40 individuals across both our pilot study and experimental manipulations;

117     anesthetized tadpoles ranged across early larval developmental stages (Gosner 24-26).

118

119     *Tadpole tagging*—We applied VIE tags to early larval stages of *D. tinctorius* and monitored

120     tadpoles across development (Fig 2) to ensure the presence of the tags over time, and to test

121     the effects of larval tagging and tag retention across metamorphosis. Previous studies

122     reporting tadpole tagging have been done primarily with late-term tadpoles (Gosner stage

123     30+) whose snout-vent lengths (SVL) were double or triple the SVL of tadpoles in our

124     experiment (Andis, 2018; Bainbridge et al., 2015; McHarry et al., 2018). Other studies also

125     worked with amphibians who produce large egg clutches (*Litoria aurea*, 37000 eggs/clutch

126     (Pyke & White, 2001); American bullfrog, 12000 eggs/clutch (Howard, 1978); *Alytes*

127     *obstetricans*, 50 eggs/clutch (Reading & Clarke, 1988)), which allowed for large tag sample

128     sizes (n = 53-90, depending on study). *Dendrobates tinctorius* lay clutches that range from 2

129     to 5 eggs with a high level of mortality (Rojas & Pašukonis, 2019). Due to the reproductive

130     limitations of the system, our sample total (n = 27 tagged, n = 11 control) is less than

131     previously published data.

132

133     Elastomer was mixed and loaded into syringes prior to each tagging session, according to the

134     Northwest Marine Technology VIE tag protocol. Elastomer was stored in a freezer (-20C)

135     during extended periods of disuse and in a refrigerator between individual tagging sessions;

136     we found that mixed elastomer was no longer effective after a storage period of longer than

137     three months. Average tagging procedure was executed in under 90 seconds. Throughout our

138     pilot study we found that tag retention was most effective when placed dorsally; thus, this

139     experiment only contained dorsally marked tadpoles. Each tadpole was marked only once.

140

141     Tadpoles were placed on a laminated surface and dried with a paper towel to improve grip; a

142     needle was placed subcutaneously and dye (approx. 1 µl) was injected. For this experiment,

143     we used a fluorescent green elastomer, though any color tag would have been suitable for

144     application. Tadpoles were placed under UV light to ensure proper placement of the tag.

145     Tadpoles post-anesthesia were placed in a pool of spring water and observed for 10 minutes

146     to ensure proper return of muscular function. After the observation period, tadpoles were

147     returned to the pool of water in which they were living.

148

149     *Statistical analysis*

150

151     *Tag retention and observation model*

152     VIE tag retention and observation was modeled using a Bayesian CJS (Cormack-Jolly-Seber)

153     survival model (see R and JAGS code in  supplementary materials; Jolly, 1965; Lebreton et

154     al., 1992; Seber, 1965). For each individual, we considered tag observation as a categorical

155     variable that was recorded as absent (0) or present (1); tags that had been lost and not re-

156     observed were marked NA after the last confirmed observation. We assessed the status of the

157     tag and tadpole development (size, weight) weekly. Tag retention was recorded as present (1)

158     for all weeks previous to the last observation and recorded as NA for all those that

159     followed.  Our coding schematic (see Fig 1) takes into account observer error as a tag that is

160     not observed at one time point but seen later in development is recorded as "retained"

161     throughout the entire unobserved period.   The retention status of the tag is unknown after the

162     last positive observation. Our model considered weekly discrete time steps where the

163     retention and observation of the tag were considered latent variables that occurred with a

164     certain probability ($\phi$ and $p$, respectively following the nomenclature commonly used for

165     CJS models).

166

$$\text{Week 1} \xrightarrow{\phi_1} \text{Week 2} \xrightarrow{\phi_2} \text{Week 3}$$
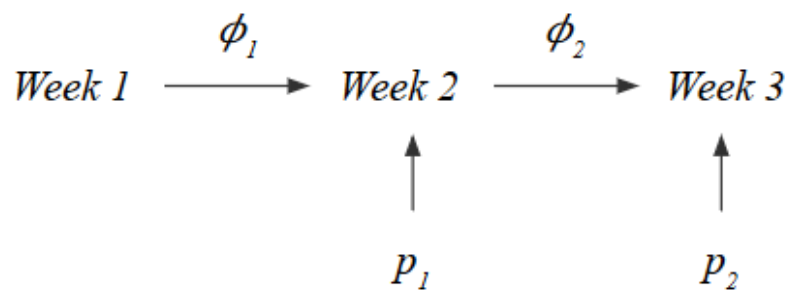
$$p_1 \qquad \qquad p_2$$

167

168    Figure 1. Schematic illustrating retention and observation variables in tag detection model.

169    Where $\phi$ is the probability and $p$ is the probability of observation. Consecutive weeks of an

170    unobserved tag were marked "retained" if the tag was found later in development.

171    We considered three possible models (M1-3) of increasing complexity for $\phi$ and $p$:

172    M1 assumed constant probabilities of observation and retention, M2 considered a week effect

173    on both probabilities using a logit link function, and M3 took into account both a week effect

174    on $\phi$ and $p$ as well as individual identity as a random effect. Tag retention and observation

175    were defined as following a binomial distribution with a probability $\phi$ and $p$ respectively for

176    all models. In models M2 and M3 retention and observation varied for each week of

177    development ($t$), thus we used a logit link function to determine $\phi$ and $p$ for each week

178    considered. In model M3 retention and observation were also influenced by individual identity

179    (*id*), to account for it, we sampled the random effect parameter estimates from a normal

180    distribution with a certain standard deviation for each individual which were later incorporated

181    to the same logit link function.

182

183    For each model we used an MCMC approach considering uninformative priors for all

184    parameters (see supplementary materials) and simulation run characteristics of 4 chains,

185    100,000 iterations with a 5,000 burn-in and a thinning of 10. Chain convergence was assessed

186    using a potential scale reduction factor (PSRF) of our parameter estimates which discarded any

187    model run that resulted in a PSRF larger than 1.1 or smaller than 0.9. We checked sample

188    independence by determining the effective sample size of each parameter.  We did not consider

189    any model run with less than 5000 independent samples for any parameter.

190

191    Model selection was based on  the lowest DIC value (Deviance Information Criterion) and

192    biological relevance.   The most likely discrete probabilities of retention and observation for

193     each week were based on the posterior distributions generated by our model, these values

194     were used to visualize the cumulative probability of tag detection across larval development.

195

196     *Tadpole growth rates*

197     Growth rates were compared between treatments using a linear mixed-effect model (LMM).

198     Weekly weight (~weight) and treatment (~treatment) were coded as additive predictors in the

199     growth rate model. Tadpole ID was used as a random effect on the intercept. Growth between

200     treatments was compared by calculating weekly rate changes across development for both

201     treatments, and then rate percent was used in model analysis which were evaluated with a

202     Kenward-Roger's method ANOVA. Growth rate models were chosen as a result of Akaike

203     Information Criterion output (AIC; Akaike, 1973).

204

205     *Tadpole survival rates*

206     We used a Kaplan-Meier survival curve to visualize treatment effect on tadpole survival.   A

207     Cox proportional hazard model was used to calculate the parameters and uncertainty of

208     tagging on survival. Survival object was parameterized with respect to death and time in

209     response to treatment (Surv(Week, Dead) ~ Treatment). Survival was coded as a binomial

210     response (alive (0), dead (1)).

211

212     All models and statistics were performed in the program R using base R (v. 3.6.1, R

213     Development Core Team, 2019) with additional packages "survival" (Therneau, 2014),

214     "dplyr" (Wickham et al., 2019), "lme4" (Bates et al., 2015), "pbkrtest" (Halekoh &

215     Højsgaard, 2014), "JAGS" (Plummer, 2003), and "R2jags" (Su & Yajima, 2015).

216

217     **Results**

218

219     *Tag success* – Out of our 27 fluorescent tags, 81 % (22/27) were successfully detected in

220     tadpoles over the first month of application. This decreased to a little over 50% (8/15)

221     detection by the third month of application, which also marks the approximate time of

222     tadpole metamorphosis. Mean weight at time of tagging was 0.12g (± 0.019 SE) for tagged

223     tadpoles and 0.099g (± 0.015 SE) for control tadpoles. Control tadpole weights ranged from

224     0.0307 to 0.18g at initial weigh-in, tagged tadpole weights ranged from 0.0318 to 0.36g at

225     time of tagging. The smallest successful tag was applied at 0.0318g, which was a tadpole

226    who had recently hatched (approximately Gosner stage 25). Our experimental tadpoles were

227    tagged in the early larval stages of development: the youngest successful tag was applied

228    on recently hatched tadpoles who had yet to be transported by their fathers. We report here

229    that tagging did not prevent transport behavior by father (n = 2), though tagging at this life

230    stage is especially delicate and requires a practiced hand. We attempted embryonic tagging in

231    pilot studies, but were not able to successfully inject the tag without permanently damaging

232    the embryo.

233

234    The model that had the lowest DIC did not include a week effect or an individual random

235    effect (M1). It is important to note that tag observation sometimes changed throughout

236    development, and tags that were not observed one week sometimes were detectable later in

237    development (see Fig 3). Instances where tags were not observed could be due to individual

238    growth, resulting in a tag being obstructed by a physical structure (i.e. muscle, tissue) for a

239    period of time. For example, the cumulative probability of tag retention ($\phi$) until the third

240    month of development was 0.61 (0.33 -0.80, 95% CI) while the cumulative probability of tag

241    observation ($p$) was 0.38 (0.16-0.59, 95% CI). On average, the difference between

242    cumulative retention and observation rates was about 15%.
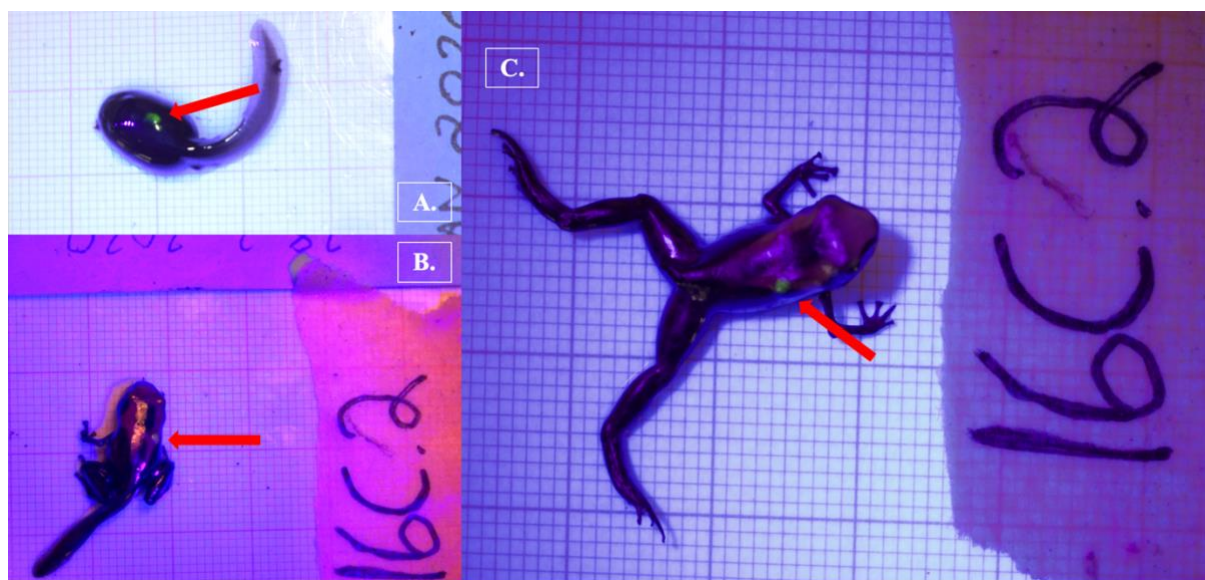
243



244

245    Figure 2. Fluorescent green VI Elastomer tag inserted dorsally on *Dendrobates tinctorius*

246    shown on the same individual as (a) a late stage larva, (b) a metamorph, and (c) a recently

247    metamorphosed juvenile. All photos taken with Nikon DS5300 DSLR on 1 x 1 mm

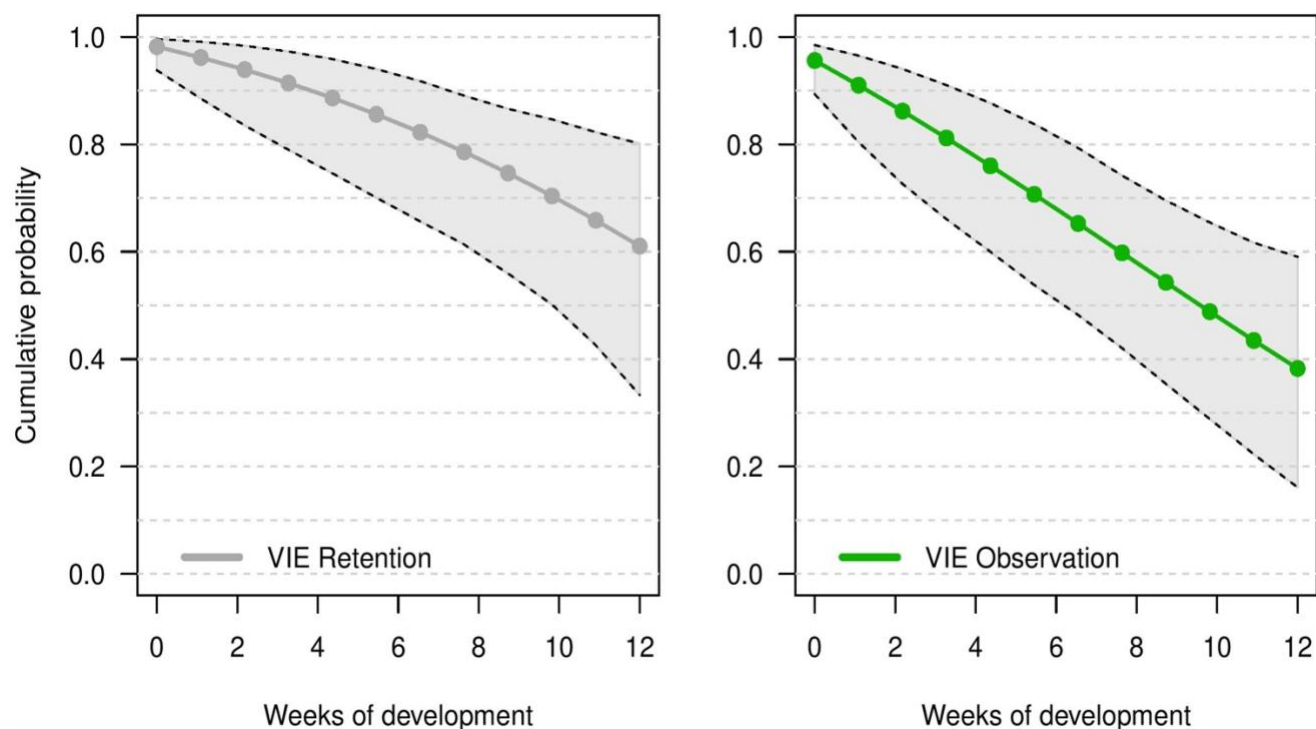248    background under UV light to enhance tag detection.

Figure 3. Estimate of the cumulative probability of tag detection across larval development for model M1. Points are posterior means. Grey points are the probability of tag retention ($\phi$) and green points are probability of tag observation ($p$) at discrete time intervals corresponding to weeks of development. Grey polygons delimited by black dashed lines indicate the 95% credible intervals.

*Growth rate* – We found no significant difference in weekly growth rate between control and tagged tadpoles (Fig 4), indicating that tagging does not affect tadpole growth (lmer, ANOVA Kenward-Roger's method, $F(1, 37) = 1.12$, $p = 0.296$). Weekly tadpole growth rate significantly decreased across time (lmer, ANOVA Kenward-Roger's method, $F(1, 415) = 56.4$, $p = 0.03563_{-11}$).
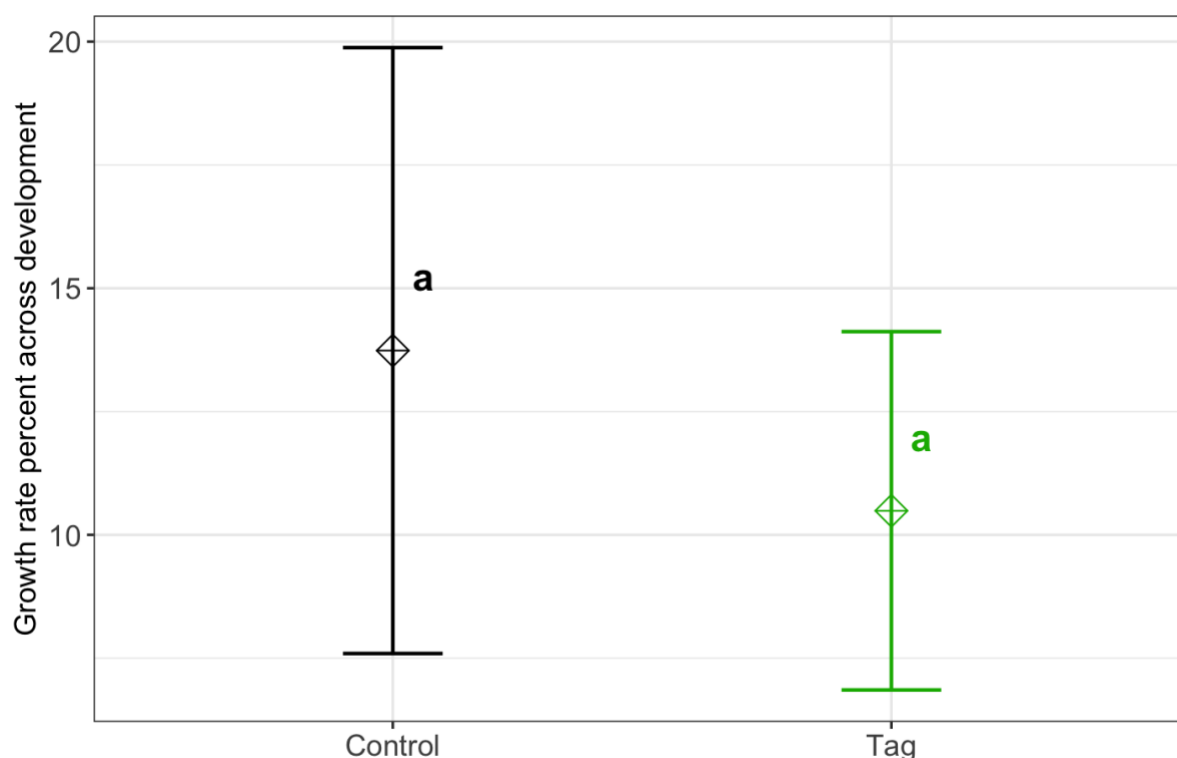
262

263   Figure 4. Average growth rate percent of VIE tagged and control groups. Diamonds represent

264   the LS mean for which error bars indicate 95% confidence intervals. Means sharing letters

265   are not significantly different (Tukey-adjusted comparisons, ANOVA Kenward-Roger's

266   method, $F(1, 37) = 1.12$, $p = 0.296$).

267

268   *Survival*— There was no significant difference in survival between control and tagged groups

269   across larval stages of development. Mortality across the first three months was 18% (n

270   $=5/27$) for tagged tadpoles and 27% (n = 3/11) for control tadpoles (Fig 5). A Cox

271   proportional hazard model did not find any significant difference in survival based on

272   treatment (Cox proportional hazards model, $z = -0.29$, $p = 0.76$). Post-metamorphic survival

273   was excluded from analysis due to unnaturally high froglet loss throughout the lab colony

274   which is not indicative of tag impact on froglet survival, but likely ineffective laboratory
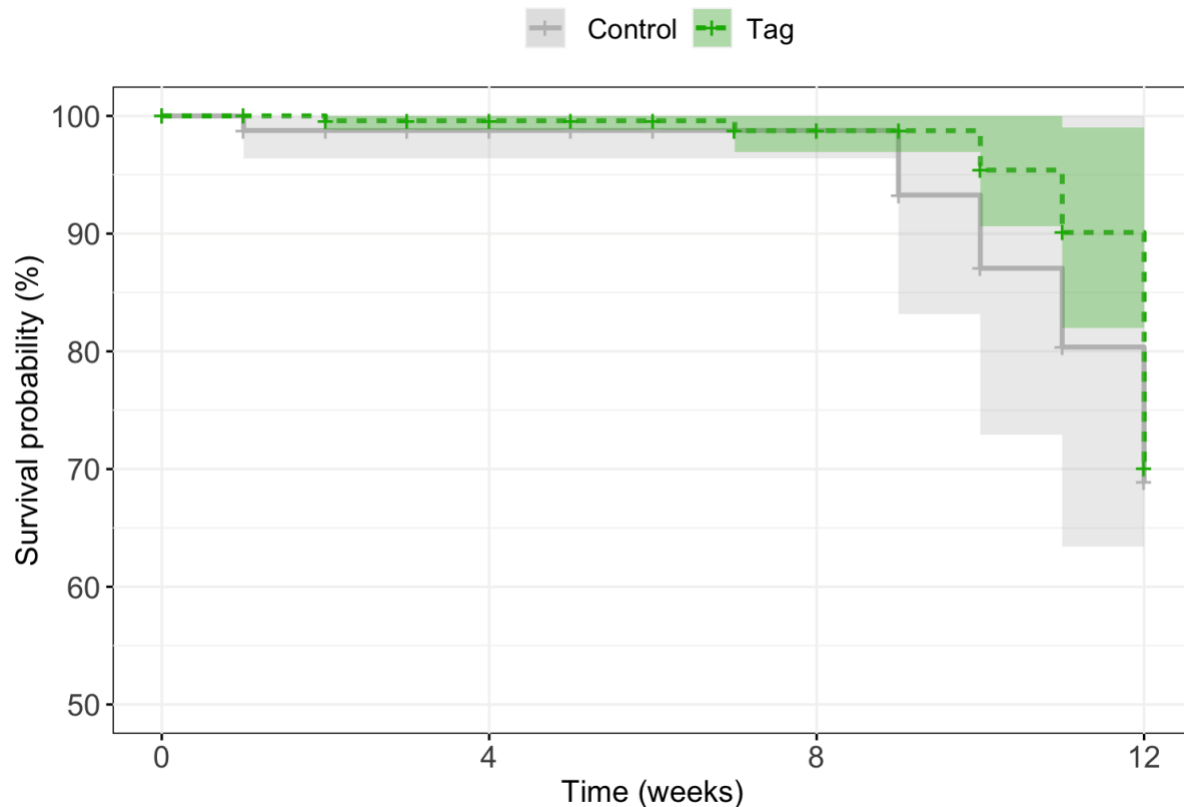
275   practices for juvenile health.

276

Figure 5. Kaplan Meier survival analysis of experimental tadpoles across larval development. A Cox proportional hazards model did not find any significant difference in treatment on tadpole survival across development ($z = -0.29$, $p = 0.76$).

## Discussion

In our study we applied VIE tags on *D. tinctorius* tadpoles and monitored them across development under laboratory conditions. Compared to previously published visible implant studies, our approach presents application at the youngest developmental stage, and is only the third study (after Bainbridge et al., 2015; Andis, 2018) to follow tags across metamorphosis. To our knowledge, this is the first attempt of larval tagging in a tropical frog, as previous work focused exclusively on species from temperate regions (Bainbridge et al., 2015: *Litoria aurea*; Courtois et al., 2013, *Alytes obstetricans;* Nauwelaerts et al., 2000, *Rana esculenta*). The successful application of VIE tags for the first time in a tropical species with elaborate parental care provides valuable opportunities to investigate parent-offspring interactions and dispersal of these species in a natural context.

296    Similar to other studies, we found no difference in growth rate or survival between tagged

297    and control treatments. Based on our weekly weigh-ins and LMM model, we did not detect

298    any significant impact of tagging on growth rates across development. Throughout our study,

299    tadpoles grew significantly faster earlier in development which could be due to laboratory

300    conditions (a high-food, no-competition environment). Given the circumstances, tadpoles

301    may have invested energy in growing early in development which would help avoid

302    predation and decrease latency to metamorphosis in the wild (Caldwell & De Araújo, 1998;

303    Rojas, 2014).  We found no effect of tagging on *D. tinctorius* survival across development;

304    however, we had high rates of post-metamorphic mortality across our laboratory population.

305    Natural history studies of *D. tinctorius* have shown high larval death rates (Rojas &

306    Pašukonis, 2019). Although our tadpoles were not subject to the same pressures as wild

307    populations, the mortality we observed across both treatments reflect the precariousness of

308    early life stages in *D. tinctorius*.

309

310    After the first month of observation, 81% of tadpoles retained their tag, which is on par with

311    retention rates reported in other tagging efforts (Anholt et al., 1998; Martin, 2011). Other

312    studies report even higher rates of success with tadpoles elastomer tags (Courtois et al., 2013

313    (100%), Bainbridge et al., 2015 (100%)) which could be due to a shorter larval period and

314    larger individuals at time of application. Retention rates of this study are of note because VIE

315    tags have been extensively used for mark-recapture studies in fishes and anurans; when

316    taking into account our tag retention rate and our tagging procedure (which takes less than 90

317    seconds), we can conclude that larval VIE mark-recapture studies on tropical amphibians is

318    feasible.

319

320    A relevant note about implant tagging is that it is limited to observer perception. As tadpoles

321    develop, morphological and phenotypic individual changes can facilitate or mask the

322    presence of a tag. Most importantly, the lack of tag observation should not be assumed to

323    indicate tag loss.  In our experiment we were able to differentiate the cumulative probability

324    of retention versus observation over time as a result of weekly checks of tag condition in

325    experimental tadpoles. Over three months of development tags could go multiple weeks

326    unobserved; finding them later in development indicated that tags were not lost, but had

327    shifted position or been re-exposed as a result of growth. This is important to take into

328    account for mark-recapture studies in settings where regular sampling or capture of the entire

329    tagged population isn't feasible. Our model estimates an average 15% difference in tag

330    observation versus retention across larval development which is an error that can be

331    incorporated as an informative prior in future tagging studies.

332

333    VIE tags come in a range of fluorescent colors, making the distinction of clutches or

334    individuals from a distinct cohort possible. This is especially relevant for the larval stages of

335    *D. tinctorius* when tadpoles are aggressive cannibals, as tagging efforts would help

336    distinguish resident tadpoles in phytotelmata. Thus, tagging could be used to help monitor

337    who is being deposited and who is getting attacked, allowing us to track interactions between

338    tadpoles in ephemeral pools (Rojas, 2015). Moreover, VIE tagging of *D. tinctorius* makes it

339    possible to successfully tag tadpoles before they are picked up and transported by their

340    parent. Elastomer tags most clearly fluoresce under low-light conditions, making them ideal

341    for their application in wild D. *tinctorius* tadpoles which live in dimly lit closed canopy

342    rainforest.

343

344    VIE tags are one of the smallest tagging methods available for field studies. With respect to

345    other tagging methods, VIA tags require a minimum SVL of 2 cm (Courtois et al., 2013) and

346    PIT tags require 4 cm (Courtois et al., 2013), making VIE tags a unique option to study larval

347    dynamics. VIE tags are not more than 4 mm in length, meaning that their successful

348    application presents new opportunities to study larval amphibians that may not have been

349    considered in the past. For example, *Anomaglossus beebei*, a small endemic poison frog from

350    Guyana, has been seen to transport tadpoles multiple times throughout development (CF,

351    personal observation). Larval tagging of this species could help decipher how shifting male

352    territories influences larval care and transport, and if newly established males take care of

353    tadpoles that are not their own. Early larval tagging could also work for *Allobates femoralis*,

354    another tadpole transporter, to understand the shifting genetic diversity within phytotelmata

355    across time (Erich et al., 2013).

356

357    Coupled with the unique patterning of *D. tincorius* that emerges in late metamorphosis and

358    settles in adulthood (Courtois et al., 2012; Rojas & Endler, 2013), tags can provide early life

359    identification that could be followed by pattern recognition, enabling individual

360    discrimination throughout an individual's entire lifespan. Bainbridge et al. (2015) report

361    recently metamorphosed VIE tag retention to be high (88-95%); we also find that tags that

362    lasted throughout larval development persisted across metamorphosis and into terrestrial life.

363    Aside from implant tagging, genetic tracking has proven to be a reliable method to follow

364    amphibian larvae throughout development into adulthood. With this said, genetic tracking

365    does not provide immediate individual detection; further, studies using this method have been

366    limited to individuals in a closed population, making the recapture of (surviving) tracked

367    individuals reasonably certain (Ringler et al., 2015). In *D. tinctorius*, however, males can

368    travel remarkable distances while carrying tadpoles (Pašukonis et al., 2019) making genetic

369    tracking a less suitable method for individual distinction in this species. Andis (2018) also did

370    remarkable work dyeing tadpoles of *Rana sylvatica* with calcein. This dye appears to persist

371    across metamorphosis, though it should be noted that their development is much shorter than

372    *D. tinctorius* and staining only allows for presence/absence detection. The presence of a VIE

373    tag (and the range of colors available for application) allows for immediate discrimination of

374    multiple groups/cohorts which may be an important advantage when conducting behavioral

375    experiments and elucidating natural history dynamics in the wild.

376

377    Our study presents a successful continuation expanding marking methodology to larval

378    tropical species. Using laboratory conditions, we were able to mimic a common scenario

379    where experimental tadpoles were left to develop in small, stable pools of water. This is

380    reflective of the most common parental behavior exhibited by *D. tinctorius*, where males

381    transport newly-hatched tadpoles to develop in small water holdings (Rojas & Pašukonis,

382    2019). Future studies in field conditions would be useful to supplement these findings. For

383    example, it will be important to understand how tadpole interaction with conspecifics,

384    heterospecifics, and predators affects tag success. However, based on previously published

385    data and the observation rates of our elastomers in this experiment, we believe that the

386    application of elastomers in the wild is already an appropriate method to distinguish tadpoles

387    for behavioral experiments. Elastomers are small, successful, and relatively easy to apply in

388    early amphibian life stages. Our study contributes to the growing body of methods-based

389    research demonstrating that visible implant elastomers are a viable tagging solution on a

390    variety of anuran species in early development.

391

392    Ethics statement: This experiment was permitted by the National Animal Experiment Board

393    (ESAVI/9114/04.10.07/2014). Raw data and R code will be available upon acceptance at the

394    University of Jyväskylä data repository. DOI xxx.

395

396    **Conclusions**

397     Differentiating individuals/cohorts can be a powerful tool when conducting behavioral

398     experiments. Often, marking animals is a technique used to distinguish individuals when

399     physical features are not distinct enough for visual differentiation. Choosing an optimal tag

400     for a system is a tradeoff between reliability and invasiveness and is often limited to product

401     cost and efficiency in identification. Elastomers (VIE) are injectable polymers that have been

402     extensively used in fish and anuran systems. However, until this point, they have been

403     applied to large larvae or adults and have been heavily biased towards common, temperate

404     species. Here, we present the first application of VIE tags on a small larval tropical frog

405     (*Dendrobates tinctorius*) and follow tag success across development. We found that (1) VIE

406     tags can be successfully applied to recently hatched tadpoles, (2) tags can be reliably

407     followed throughout larval development and sometimes retained across metamorphosis, and

408     (3) VIE tags do not appear to interfere with parental care behavior (i.e. tadpole transport).

409     Our study expands the application of tagging to early developmental stages in tropical

410     amphibians which can be of use in behavior, conservation, and natural history research

411     studies in the future.

412

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