

1 VISIBLE IMPLANT ELASTOMER (VIE) SUCCESS IN EARLY 2 LARVAL STAGES OF A TROPICAL AMPHIBIAN SPECIES

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4 Chloe Fouilloux*¹, Guillermo Garcia-Costoya¹, and Bibiana Rojas¹

5 ¹Department of Biology and Environmental Science, University of Jyväskylä, Finland

6 Corresponding Author:

7 Chloe Fouilloux*¹

8 Email address: chloe.a.fouilloux@jyu.fi

9

10 Abstract

11

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

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33 Introduction

34

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

46

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

63

64 Understanding the dispersion dynamics and survival of anurans from aquatic to terrestrial
65 habitats makes developmentally early larval tagging especially interesting. For example,
66 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 ($\pm 2C$) 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 1 μ L: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 μ l) 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

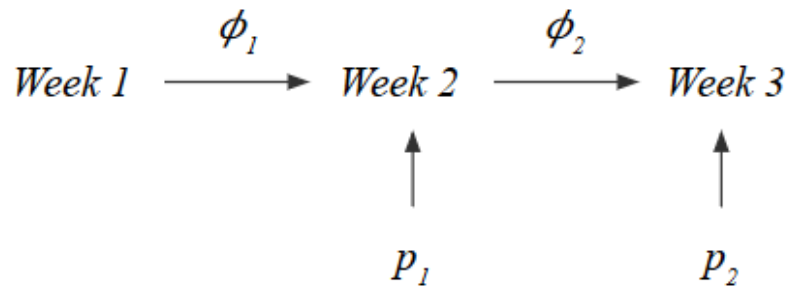
149 *Statistical analysis*

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 (ϕ and p , respectively following the nomenclature commonly used for
165 CJS models).

166



167

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

169 Where ϕ 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 ϕ 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 ϕ 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 ϕ 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 ϕ 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**

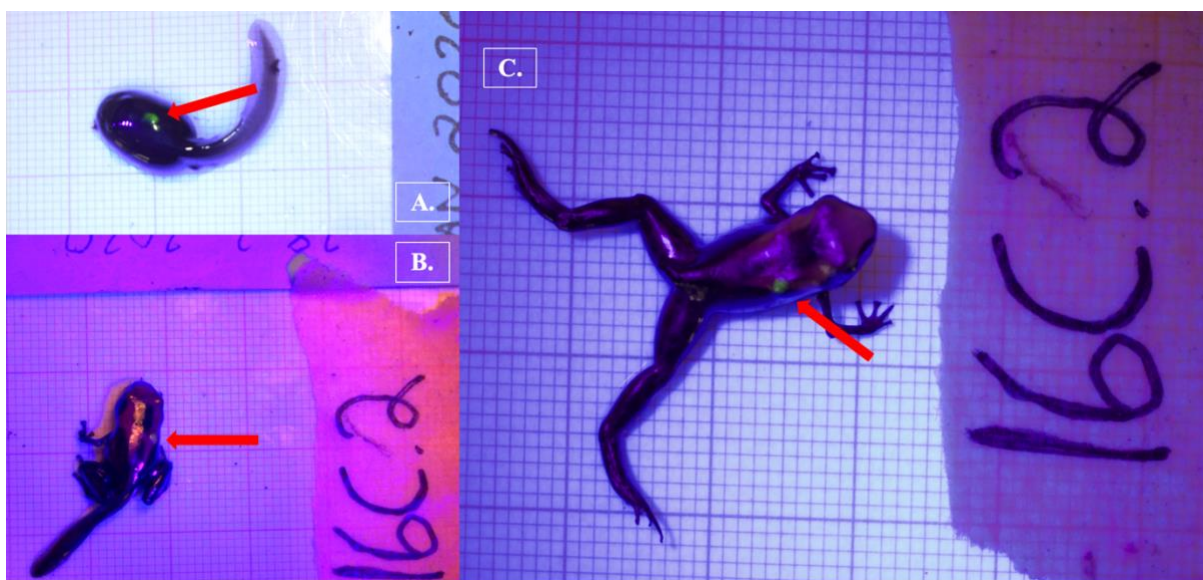
218
219 *Tag success* – Out of our 27 fluorescent tags, 81 % (22/27) were successfully detected in
220 tadpoles over the first month of application. This decreased to a little over 50% (8/15)
221 detection by the third month of application, which also marks the approximate time of
222 tadpole metamorphosis. Mean weight at time of tagging was 0.12g (\pm 0.019 SE) for tagged
223 tadpoles and 0.099g (\pm 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

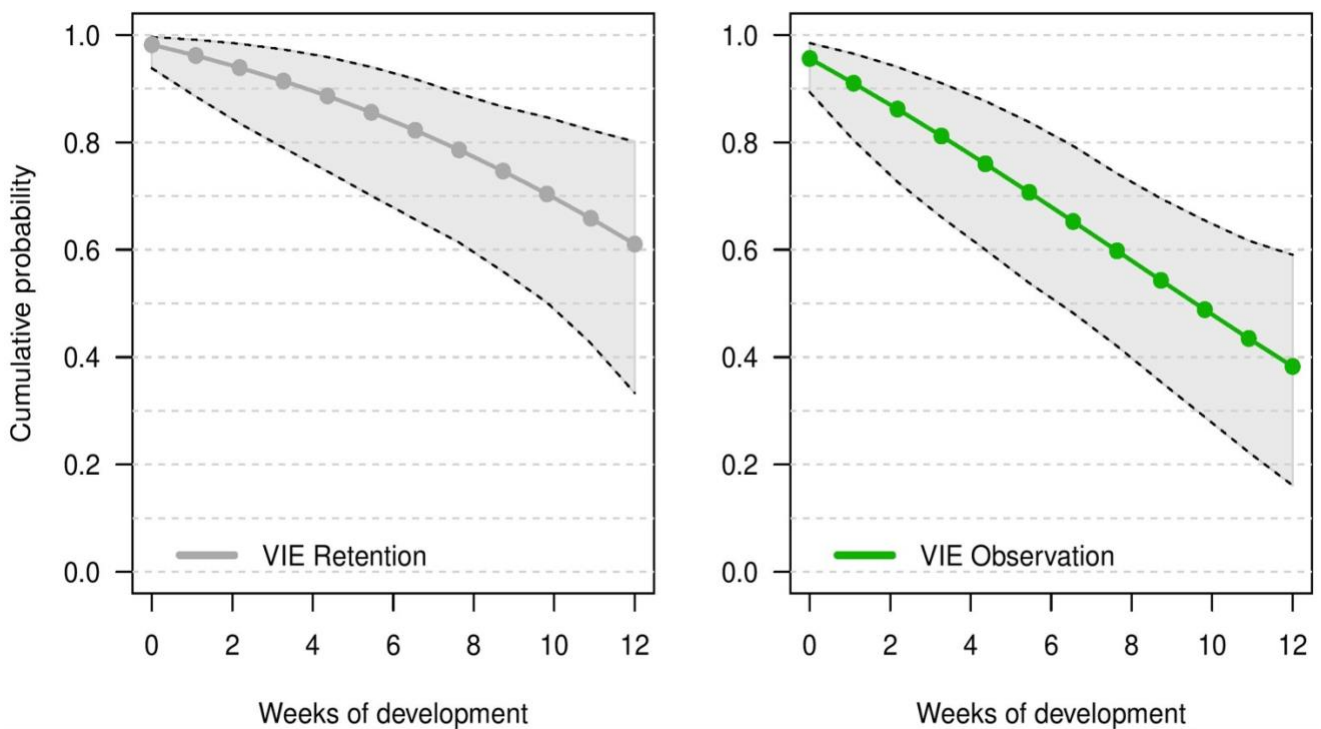
234 The model that had the lowest DIC did not include a week effect or an individual random
235 effect (M1). It is important to note that tag observation sometimes changed throughout
236 development, and tags that were not observed one week sometimes were detectable later in
237 development (see Fig 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 (ϕ) 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.



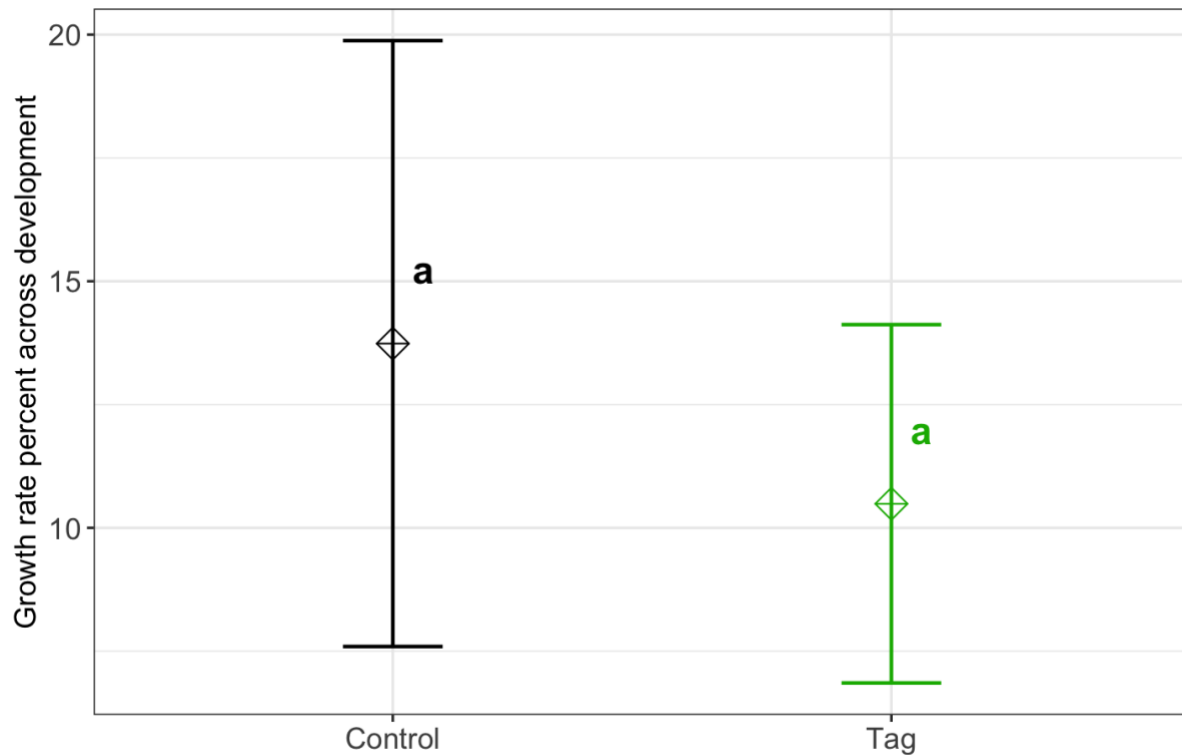
249

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

255

256 *Growth rate* – We found no significant difference in weekly growth rate between control and
257 tagged tadpoles (Fig 4), indicating that tagging does not affect tadpole growth (lmer,
258 ANOVA Kenward-Roger’s method, $F(1, 37) = 1.12, p = 0.296$). Weekly tadpole growth rate
259 significantly decreased across time (lmer, ANOVA Kenward-Roger’s method, $F(1, 415) =$
260 $56.4, p = 0.03563_{-11}$).

261



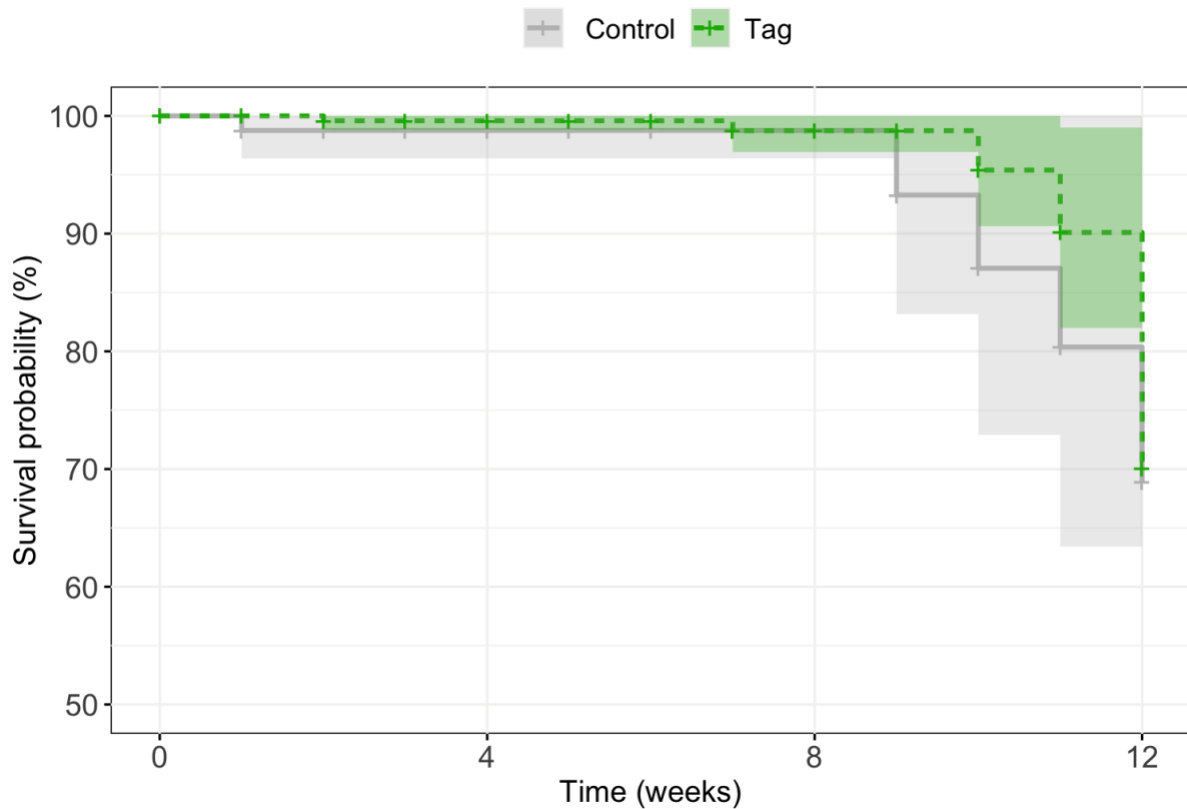
262

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



277
278

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

282

283 Discussion

284

285 In our study we applied VIE tags on *D. tinctorius* tadpoles and monitored them across
286 development under laboratory conditions. Compared to previously published visible implant
287 studies, our approach presents application at the youngest developmental stage, and is only
288 the third study (after Bainbridge et al., 2015; Andis, 2018) to follow tags across
289 metamorphosis. To our knowledge, this is the first attempt of larval tagging in a tropical frog,
290 as previous work focused exclusively on species from temperate regions (Bainbridge et al.,
291 2015: *Litoria aurea*; Courtois et al., 2013, *Alytes obstetricans*; Nauwelaerts et al., 2000, *Rana*
292 *esculenta*). The successful application of VIE tags for the first time in a tropical species with
293 elaborate parental care provides valuable opportunities to investigate parent-offspring
294 interactions and dispersion of these species in a natural context.

295

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. tinctorius* 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

413 **Acknowledgements**

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418

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