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NOTES ON THE DISTRIBUTION AND INVASION POTENTIAL OF *ACHATINA FULICA* BOWDICH, 1822 (GASTROPODA: PULMONATA: ACHATINIDAE) IN ECUADOR

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Abstract: Distribution data on *Achatina fulica* Bowdich were obtained from pest control agencies and from a survey of potential localities randomly distributed in all provinces of Ecuador. Among the total of 1,236 localities, 1,065 (86.2%) held populations of the species. The snail was found to spread much faster than predicted and was present in areas not previously suspected to be under the risk of invasion. The most endangered and infested areas were the coastal and Amazonian regions of the country. According to the pest control reports from government agencies, *A. fulica* most often affected plantations of cocoa (24.8% of localities), plantain (11.8%) and banana (11.2%), but was also known to forage on 56 other species of cultivated plants. The survey of likely habitats in random localities showed a high infestation rate; urban and ruderal sites turned out to be important but largely neglected dispersal hotspots for the species. Regular observations on two populations in the city of Puyo (Pastaza province, Amazonia) showed that the growth rate and population density were high: reaching adult size took on average four weeks.

Key words: *Lissachatina fulica*, pest, invasive species, Neotropical, alien species, El Niño

INTRODUCTION

Achatina (*Lissachatina*) *fulica* Bowdich, 1822 is native to Africa and introduced into tropical regions worldwide (Raut & Barker 2002). The species is regarded as the world's most important mollusc pest of agricultural crops and an important vector of plant pathogens (e.g. Raut & Barker 2002). It is among the top hundred of globally invasive species (Lowe et al. 2000). The presence of *A. fulica* in populated areas may also threaten human health, since the species is an intermediate host of dangerous parasites, including nematodes of the genus *Angiostrongylus* as well as some schistosome platyhelminths (e.g. De Andrade-Porto et al. 2012, Vázquez & Sánchez 2014).

First reported from South America in the 1980s, *A. fulica* was then recorded from Argentina, Brazil, Colombia, Ecuador, Paraguay, Peru and Venezuela (Thiengo et al. 2007, Vogler et al. 2013). The first records in Ecuador, of 2005 (Correoso 2006, Borrero et al. 2009, Correoso & Coello 2009), pertained to a few localities within the agricultural landscape of the western, coastal, part of the country west of the Andes (Borrero et al. 2009).

According to the published statistical models which predicted the occurrence of *A. fulica* in South America (Borrero et al. 2009, Correoso & Coello 2009, Vogler et al. 2013), the species should mainly occur in western Ecuador and should not spread east of the Andes. Nevertheless, in July 2014 the snail was found far outside the boundaries predicted by the models – in the Amazonian city of Puyo (Pastaza Province) (Gołdyn et al., in press). The observation raised some serious concerns about the rate and intensity of the species' invasion. Thus, all provinces of Ecuador were surveyed for the occurrence of *A. fulica* and information on its presence in the crops was obtained from local governmental plant protection agencies. Moreover, a regular monitoring of the pest's populations was started in Puyo, using marking-release-recapture method.

This paper deals with preliminary results of our study. We describe the distribution of *A. fulica* in Ecuador and draw conclusions regarding the major crops affected by the pest. We also present data on the population structure and growth rate of the species in Puyo during the first period of observations.

MATERIAL AND METHODS

Information on the distribution of *A. fulica* in Ecuador was gathered in two ways. First, data on the snail's occurrence were obtained from the Ministerio de Agricultura, Ganadería, Acuacultura y Pesca [MAGAP; Ministry of Agriculture, Livestock, Aquaculture and Fisheries], the governmental agency which collects reports on pests from farmers and agricultural companies. In total, the MAGAP information accounted for 1,002 localities of *A. fulica*. Since some of the provinces of Ecuador were not covered by the data or the information was not collected randomly and independently, an additional survey focused especially on the regions not covered by or sparsely represented in the MAGAP data. The localities selected for the survey (234 in total) were randomly scattered across such provinces; habitats fitting the preferences of *A. fulica* in these localities were checked for its occurrence. Data on crop, habitat type and general geographical location (latitude, longitude, altitude) were recorded for each locality. The survey was conducted in August 2015 – March 2016 and covered both rainy and dry seasons.

Population structure and dynamics were monitored in two populations of *A. fulica* in the city of Puyo (Pastaza province, 01°29'00"S, 78°00'00"W). The city is located in western Amazonia, on the outer flanks of the Eastern Cordillera of the Andes at the altitude of 924 m a.s.l. It is situated on the Puyo River, a tributary to the Pastaza River which eventually falls into the Amazon River. The city has a rainy tropical climate – the average temperature is 20.8°C and ranges between 13.7° and 29.2°C. The mean annual precipitation is 4,524.7 mm, the monthly precipitation being 328 mm in the dry season and 398 mm in the rainy season. During the El Niño years, however, the precipitation differences between the seasons become slightly more pronounced (Palacios Tapia et al. 2014).

The snail populations were monitored once a week, during early night hours. Each control lasted for one hour during which all the snails found were individually marked with unique numbers. Their shell height and width were measured with callipers. The location of each snail was recorded using a GPS device. Population abundance was calculated based on recapture data using the Chapman estimator (Chapman 1951). The data presented here cover four weeks of the 2015 dry season (August–September) during an El Niño year.

RESULTS AND DISCUSSION

The MAGAP provided data on the distribution of *A. fulica* in 1,002 localities in 17 out of the 22 Ecuadorian provinces (Fig. 1). Most of those were located in the coastal and Amazonian regions of the country, with only few records from the provinces dominated by the mountainous landscapes of the Andes. The coastal provinces most affected by the pest were Santo Domingo de los Tsáchilas, Los Ríos, Guayas, Santa Elena and El Oro (269 localities), and in the Amazonian region they were Zamora-Chinchipe, Morona-Santiago, Pastaza and Napo (446 localities). The occurrence of *A. fulica* was strongly negatively correlated with the altitude above sea level (Spearman's rank correlation: $r = -0.8903$; $p < 0.001$) and there were no reports of the snail above 2,696 m a.s.l.

Among the localities listed by MAGAP as infested by *A. fulica,* cocoa (*Theobroma cacao*) plantations were reported most often as being affected, constituting 24.8% of all the localities. The second most frequent crops were plantain (*Musa paradisiaca*) and banana (*Musa acuminata*) – 11.8% and 11.2% of all the localities, respectively; both *Musa* species combined constituted 23.0% of the agricultural sites cov-

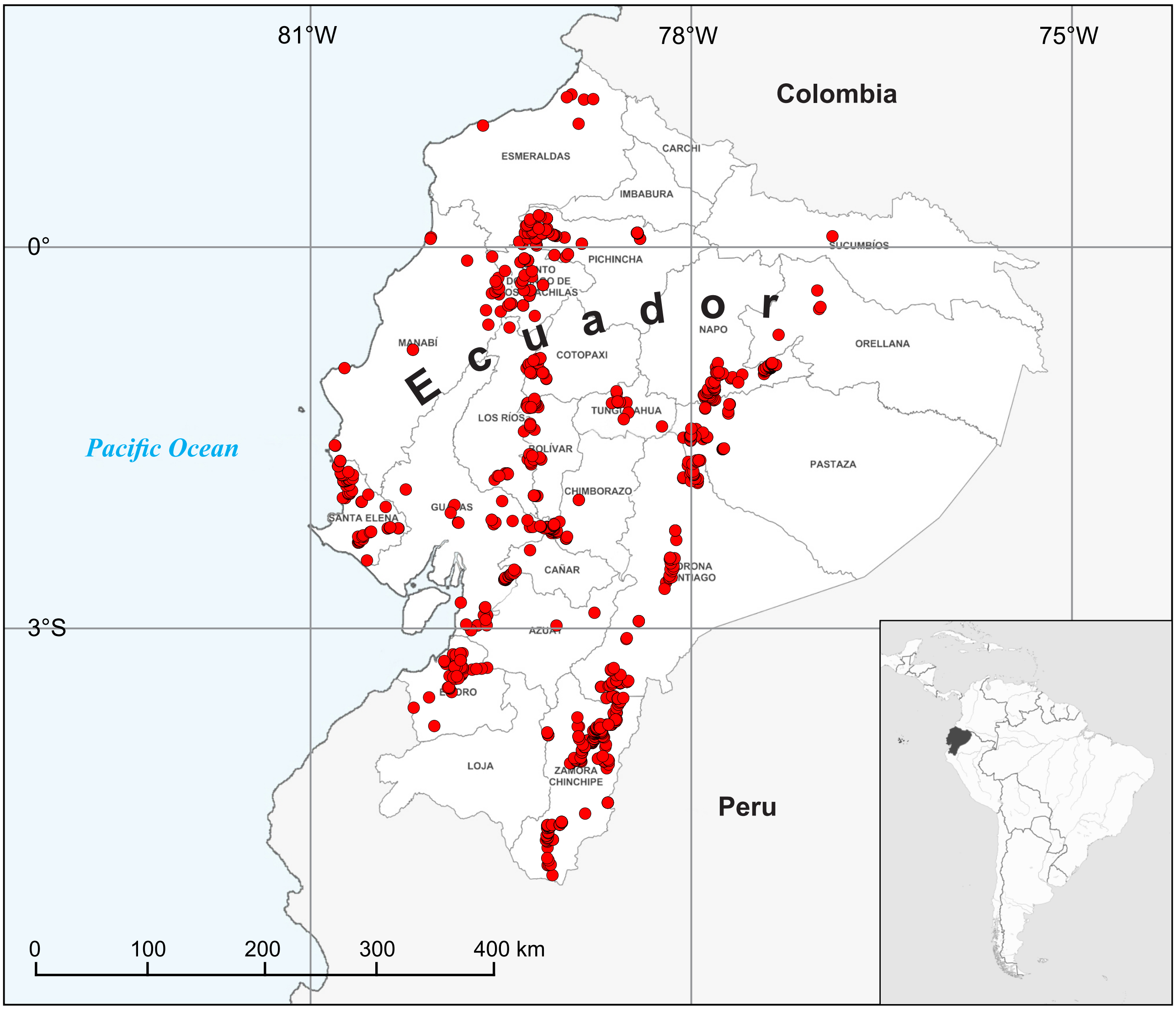

Fig. 1. Distribution of known localities of *A. fulica* in Ecuador

ered by the data. Other important crops, less often infested by the snails, were pineapple (*Ananas comosus*; 4.5%), sugar cane (*Saccharum officinarum*; 4.2%), pitahaya (*Hylocereus undatus*; 3.0%), Chinese hibiscus (*Hibiscus rosa-sinensis*; 3.0%), papaya (*Carica papaya*; 2.6%), lemon (*Citrus limon*; 2.3%), coffee (*Caffea arabica*; 2.3%), tangerine (*Citrus nobilis*; 2.2%), cassava (*Manihot esculenta*; 2.0%) and maize (*Zea mays*; 2.0%). In total, *A. fulica* occurred on 59 species of cultivated plants, with a clear preference for fruit crops.

The results of our field survey agree with the conclusions on the distribution of *A. fulica* based on the MAGAP data – out of the 234 potential localities with habitats likely to harbour the species, *A. fulica* was found in 63 sites (26.9%). All the records were located within the coastal (n = 26) and Amazonian (n = 37) provinces, with no infested sites recorded above 2,300 m a.s.l. in the Andean part of the country. Slight differences with regard to the preferred habitat type were observed between the two datasets. In our set most of the sites represented urban (n = 23) and ruderal habitats (n = 18) and, among agricultural occurrences, banana (n = 12) was the most frequently infested crop. Other cultivated plants attacked by *A. fulica* included papaya (n = 5), cocoa (n = 3) and pineapple (n = 2).

The presently known distribution pattern of *A. fulica* in Ecuador partially contradicts the predictions of the models proposed in the literature. Based on the models, the species should occur mainly in western Ecuador and should not be found east of the Andes. The most pessimistic scenario (Correoso & Coello 2009) and one of the models proposed by Vogler et al. (2013) assumed a slight probability of some occurrences in the Amazonian part of the country, next to the border with Peru. We found that the Amazonian provinces were actually among the most heavily infested regions of Ecuador, next only to the lowland plains of the south-eastern, coastal provinces. Another prediction of the cited models was that *A.*

fulica should not occur at altitudes exceeding 2,500 m a.s.l. Overall, our data support this prediction – only 12 (1.1%) out of the 1,065 localities were located above 2,500 m a.s.l. and the highest occurrence was 2,696 m a.s.l. Thus, altitude seems to be the major limiting factor for the occurrence of *A. fulica* in Ecuador, probably because of the low temperatures which are typical of higher elevations. While the mean temperature in the coastal and Amazonian regions of the country are 26.5°C and 24.3°C, respectively, much lower temperatures are typical of the Andean part; they average 15.6°C for Quito (capital of the country; 2,850 m a.s.l.) and even subzero at higher locations (PALACIOS TAPIA et al. 2014).

While our data support the thesis that *A. fulica* is a major pest in tropical agriculture and infests various plant species, our survey of random localities shows that urban and ruderal sites are among most important habitats of the species. On the other hand, such habitats were largely neglected by the pest control agencies. None of the records provided by MAGAP was urban. In such sites, *A. fulica* feeds predominantly on faeces of domestic animals, organic garbage and fruit (GOŁDYN et al., in press). Despite the lack of direct influence of such populations on the economy, they pose an important hazard for human health and constitute potential hotspots for the species' spread to new agricultural areas. Urban sites should be therefore included in eradication programmes and control actions. Moreover, data on the biology and population ecology of *A. fulica* in urban localities should be regarded as a crucial tool in the future control programmes.

The two monitored populations in Puyo are abundant, with the densities (Chapman estimator) of 22.9 and 3.7 individuals per square metre. The values are much greater than some densities reported in the literature. Under similar conditions of a Neotropical urban environment, 0.07 ind./m² were recorded in the Brazilian Ilha Porchat (MIRANDA et al. 2014), 0.06–8 ind./m² in N.E. Brazil (ALBUQUERQUE et al. 2008), and 0.00015 ind./m² in Havana, Cuba (VÁZQUEZ & SÁNCHEZ 2014). On the other hand, the mean density recorded in Puerto Iguazú City, Argentina, was considerably higher and amounted to 107.6 ind./m² (GUTIÉRREZ GREGORIC et al. 2011). The estimates from the preceding year in adjacent localities in Puyo, using a different method, showed densities of 1–41 ind./m² (GOŁDYN et al., in press). The abundance of the studied populations was fairly high, confirming the status of the urban localities as potential important dispersal hotspots, threatening agricultural areas of the region.

The shell height in the studied populations varied between 24.6 and 94.4 mm (mean = 58.35; median = 58.7; SD = 11.629). Compared with the results from the previous dry season, the snails had shells on average by 1 cm larger than during the previous study, when the mean height was 48.9 mm (GOŁDYN et al., in press). Contrary to the previous measurements, there was no significant prevalence of small individuals among the snails (Fig. 2; Skewness = –0,138; Kurtosis = 1,048). Since the current measurements were performed during the El Niño year (the phenomenon in 2015/2016 was one of the strongest in history; TOLLEFSON 2016), it is possible that the reduced number of juveniles could reflect the influence of El Niño on the populations of *A. fulica*. The effect of climate changes on the risk of the species' invasion in India was recently discussed by SARMA et al. (2015).

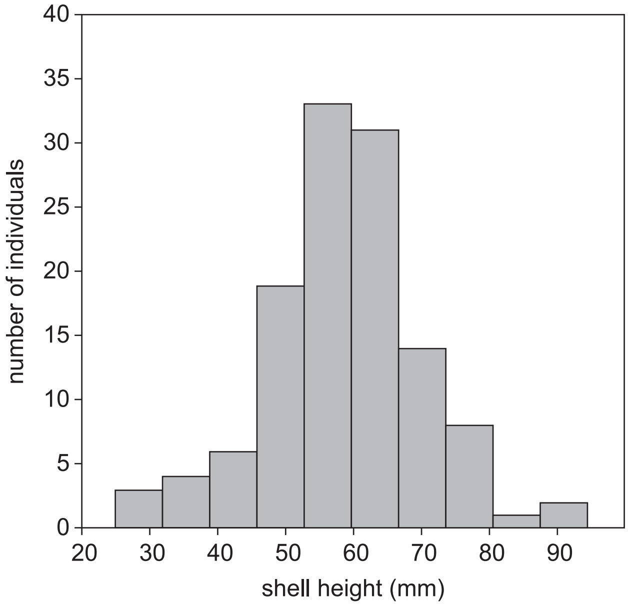

Fig. 2. Size structure of the two populations of *Achatina fulica* in Puyo, Amazonian Ecuador

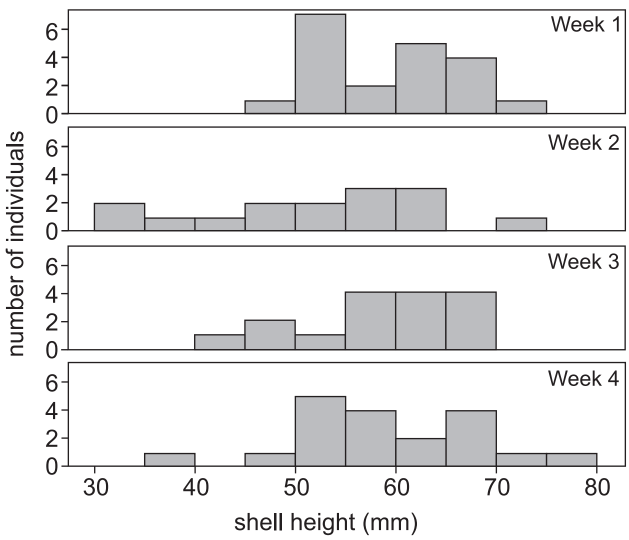

Fig. 3. Changes in size structure of one of the populations of *Achatina fulica* sampled during four weeks of 2016 in Puyo, Amazonian Ecuador

The population age structure during the four week period of observations is shown in Fig. 3. Small (and presumably young) snails were observed only during the second week of the study, indicating that a reproduction event took place before the second sampling. Growth in terms of shell height was seen in consecutive weeks, suggesting that in three weeks the snails could grow from 3 to 5 cm. *A. fulica* reaches maturity long before growth is completed and individuals with shells 5 cm high were observed to lay eggs (Mead 1961 and personal observation). Therefore it can be assumed that the time between hatching and maturation in the conditions of Ecuadorian Amazonian dry season is three to four weeks.

CONCLUSIONS

Our study shows that the invasion of *A. fulica* in Ecuador is much more rapid than previously thought. Reports not older than 10 years list less than 20 occurrences of the snail in the country, assuming that in the near future the pest should be present only in the coastal regions of Ecuador (Correoso 2006, Borrero et al. 2009, Correoso & Coello 2009). Our data of 2015 and 2016 provide 1,065 localities in total, with the infestation rates assessed by rapid survey at 26.9% of potential localities sampled. Moreover, our research shows the importance of urban habitats which are largely neglected in the pest control. The growth rate and population density in such conditions can be high and, besides the health hazard that the species represents, such sites may constitute important hotspots for dispersal to agricultural areas. Thus, measures taken to stop or at least slow down the invasion should include eradication of *A. fulica* from urban and ruderal localities as one of the major steps. First of all, however, raising awareness about the pest in local human communities is needed. Reports on new localities of the species obtained from regular residents of particular regions of Ecuador would be an invaluable source of information – especially important in the early phase of invasion, when new populations may still be controlled and eradicated relatively easily.

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