Abstract
In addition to El Niño events, which can alter the pelagic food chain that supports growth and survival of sea lions, dog overpopulation, and diseases can cause further population declines in sea lions on the Galapagos. Knowledge of baseline data and evaluation of existing strategies to control dog reproduction are required for effective management of dog overpopulation on the archipelago. The main objective of the study reported here was to estimate the human: dog ratio on Santa Cruz Island, Galapagos in September 2018. In addition, dog demographic data were used to model the expected annual dog population growth in the next 3 years. The observed human: dog ratio was 756:187 (or 4.04:1) which extrapolates to 3,886 dogs; an increase of 55% in the dog population on Santa Cruz Island from 2014 to 2018. Study results show that current spay-neuter efforts (about 180 dogs per year in the last 5 years; 57% females, 43% males) are not enough to keep the dog population stable (i.e., current baseline of 3,886 dogs in 2018). Our results justify a revision of current management action plan to control dog reproduction on Santa Cruz Island, Galapagos.

KEYWORDS
canine ecology, dog overpopulation, Galapagos

1 | INTRODUCTION

In addition to El Niño events, which can alter the pelagic food chain that supports growth and survival of sea lions (Riofrío-Lazo et al., 2017; Trillmich, 2014), dog overpopulation and diseases can cause further population declines in sea lions on the Galapagos. Because dogs have access to beaches, there is potential exposure and risk of canine distemper virus (CDV) transmission and subsequent mortality in beach-dwelling sea lions. Currently, although there are no feral dogs on the Galapagos, domestic dogs that range freely can be a threat to endemic species because they can colonize remote areas of inhabited islands and establish new feral dog populations (Reponen et al., 2014). In the past, observational studies concluded that feral dogs can prey on marine iguanas on the Galapagos (Kruuk and Snell, 1981). Furthermore, the risk of potential outbreaks of CDV in dogs on the Galapagos (which can potentially spill over to marine mammals and cause mortality) is not negligible (Diaz et al., 2016; Diaz et al., 2018). In 2001, an outbreak of CDV killed more than 600 dogs on Santa Cruz and Isabela Islands,

This is an open access article under the terms of the Creative Commons Attribution License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited.

© 2020 The Authors. Conservation Science and Practice published by Wiley Periodicals, Inc. on behalf of Society for Conservation Biology
Galapagos (Levy et al., 2008). On both islands, the suspected cause of the outbreak was the illegal introduction of infected dogs. In a recent study (Denkinger et al., 2017), lung and placenta tissue samples from Galapagos sea lions tested positive for CDV by polymerase chain reaction; the source of exposure was not confirmed.

Accurate dog population data are important for policymakers to justify and allocate adequate resources to manage the dog population on the Galapagos. In September 2014, the observed human:dog (HD) ratio on Santa Cruz Island was 6.14:1, which extrapolated to 2,503 dogs (Diaz et al., 2016). In September 2016, the observed HD ratio on Santa Cruz was 4.77:1 (3,290 dogs) (Diaz et al., 2018); an increase of 31% in the dog population from 2014 to 2016. In that study, using dog population’s demographics on Santa Cruz from 2014 and 2016, a decline in the dog population below baseline levels (i.e., 3,290 dogs in 2016) was estimated to occur 5 years after, if 500 dogs that underwent surgery every year were females. In 2016, 85 female dogs were spayed on Santa Cruz. To our knowledge, no other published research reports have estimated the dog population or measured dog population trends on the Galapagos.

The Galapagos Biosecurity Agency (ABG) is responsible for regulating, controlling, and preventing the introduction and dissemination of introduced species that represent a hazard to endemic species and their habitat—and humans on the archipelago. The ABG advocates for responsible pet ownership. A current management plan to control dog reproduction is focused on community education and promotion of spay-neuter procedures in domestic dogs in partnership with local and international conservation and animal health organizations. A current legislation recommends but does not require all dogs to be spayed or neutered. The main objective of the study reported here was to estimate the observed HD ratio on Santa Cruz Island, Galapagos in September 2018. In addition, dog demographic data were used to model the expected annual dog population growth in the next 3 years.

2 METHODS

The study received approval from the University of Florida’s Institute of Animal Care and Use Committee (protocol # 201609271).

2.1 Study site and study population

The study was conducted on Santa Cruz Island, Galapagos, during 17–26 September 2018. Santa Cruz is the main tourism hub for all of Galapagos, and it has the largest human population. In 2015, the estimated human population was 15,701 (about 12,213 people distributed on 16 neighborhoods and 2,468 households in the urban parish of Puerto Ayora and 3,488 people in the two rural neighborhoods of Bellavista and Santa Rosa) (Ecuador’s Instituto Nacional de Estadística y Censos, 2015). Santa Cruz was selected for this study to measure and compare HD ratio estimates between 2014 (6.1:1) (Diaz et al., 2016), 2016 (4.7:1) (Diaz et al., 2018) and 2018.

2.2 Sampling approach

This study targeted the same urban neighborhoods and blocks and rural neighborhoods included in dog surveys conducted on Santa Cruz Island in September 2014 (Diaz et al., 2016) and September 2016 (Diaz et al., 2018). Briefly, eight of 16 urban neighborhoods and one to four blocks within each selected neighborhood were randomly selected. Within each selected block, all households inhabited by people were included. All selected households were visited once. The same approach was used in the rural neighborhood of Bellavista, which includes four sections: Bosque, Miramar, Thomas, and Jardines. The rural neighborhood of Santa Rosa was not included because of time limitations.

2.3 Data collection

With the assistance of ABG, households were visited every day from 16.30 hr to 19.30 hr during a 10-day period, and the following data were collected from each study household: neighborhood name, residence (rural, urban), block number, house number, current number of dogs and people who live in the household, number of born or dead dogs in the last 12 months, and number of dogs in 2017. In households with ≥1 dogs, the following additional data were collected from each dog: dog’s name, age, gender, and spayed/neutered (yes, no). Finally, additional collected data included the annual number of dogs that were spayed-neutered on Santa Cruz Island during 2014–2018 (Internal Report, Agencia de Regulación y Control de la Bioseguridad y Cuarentena para Galápagos, 2017).

2.4 Data analysis

The null hypotheses that the proportions of households, households with ≥1 dogs, households with one, two, or ≥ three dogs, and spayed/neutered dogs were not different in urban and rural neighborhoods were tested by using a chi-square test. Among female dogs and male
dogs, the frequency of spayed and neutered dogs was compared between age groups (≤11 months old, 1–2 years old, 3–14 years old) by using a chi-square test. Values of \( p < .05 \) were considered significant.

The observed HD ratio was calculated by dividing the total number of people by the total number of dogs in study households.

2.4.1 Expected annual dog population growth

The 2016 population growth agent-based model (Diaz et al. 2018) was updated using new dog demographic data collected in 2018. The general structure is the same as that presented by Diaz et al. (2018) and Yoak et al. (2016). Broadly, an agent-based model was constructed in which dogs bred and died at local estimated rates, and a sterilization control scheme was overlaid to assess impacts. Because these events occur stochastically, informed by their observed rates, there is moderate variation between model runs on the exact outcomes due to chance. The new model includes two notable changes based on new data collected in 2018. The survival rate no longer differentiates between puppies and adults but instead is set to a yearly survival rate of 72.8% for all dogs. Since the last survey (Diaz et al. 2018), approximately 180 dog sterilizations were performed on Santa Cruz each year, and the known dog population increased from ~3,290 (September 2016) to ~3,886 (September 2018). These data were used to alter the proportion of females that bred each year from 30% to 35% (Figure SS1) as this approach produced a more accurate fit. These updated model parameters were used for two experimental scenarios, one in which 180 dog sterilizations were performed annually and another in which 550 were performed instead. Within each scenario, the proportion of spayed females was altered from 50% to 100% (at 10% intervals). Each arrangement which was repeated for 1,000 runs to ensure model variability was sufficiently captured and ran until either: 3 years had passed, the dog population had gone above 5,000 (an out of control scenario).

3 RESULTS

One hundred and ninety six of 332 households (59%) were surveyed. One hundred and thirty six households (41%) were not surveyed because family members were not present the day the household was visited. The proportion of surveyed households was similar in urban neighborhoods (129/223 or 58%), compared to rural neighborhoods (67/109 or 61%) (\( p = .52 \)).

3.1 Dog demographics

Overall, the proportion of households with \( \geq 1 \) dogs = 113/196 or 58%. The proportion of households with \( \geq 1 \) dogs was higher in rural neighborhoods (45/67 or 67%), compared to urban neighborhoods (68/129 or 53%) (\( p = .05 \)).

Among 113 households with dogs, most households had one dog (67 or 59%); other households had two dogs (27 or 24%) or three to nine dogs (19 or 17%). The proportions of households with 1, 2, or \( \geq 3 \) dogs were not different (\( p = .73 \)) between rural neighborhoods (28/45 or 62%; 9 or 20%; 8 or 18%, respectively) and urban neighborhoods (39/68 or 57%; 18 or 26%; 11 or 16%, respectively).

The study sample included 33/187 (18%) dogs ≤11 months old, 39 (21%) 1–2 years old, and 115 (61%) 3–14 years old; 87 (47%) males and 100 (53%) females, and 45 (52%) neutered males and 63 (63%) spayed females (Table 1). The age distribution (3–14 years old) of dogs was different (\( p < .01 \)) between urban dogs 61/115 or 53% and rural dogs (20/72 or 28%). Among female dogs, the frequency of spayed dogs was different (\( p < .01 \)) between dogs ≤11 months-old (2/14 or 14%), 1–2 years-old (23/42 or 55%), and 3–14 years (38/44 or 86%). Among male dogs, the frequency of neutered dogs was different (\( p < .01 \)) between dogs ≤11 months-old (2/19 or 11%), 1–2 years-old (15/31 or 48%), and 3–14 years (28/37 or 76%).

3.2 Human:dog ratio

The observed HD ratio in the study sample was 756:187 (or 4.04:1) (Table 2). The HD ratio was lower in rural neighborhoods (3.47:1), compared to urban neighborhoods (4.40:1). Overall, in a human population of 15,701, the observed HD ratio indicates that the dog population was 3,886 on Santa Cruz in September 2018.

Observed HD ratio data over the last 4 years on Santa Cruz indicate the dog population have increased by 55% (HD ratio = 6.14, 2,503 dogs in 2014) (HD ratio = 4.04; 3,886 dogs in 2018) (Table 3). In addition, the number of households with \( \geq 1 \) dogs increased from 66/166 or 40% (95% CI = 33, 47%) in 2014 to 113/196 or 58% (95% CI = 51, 64%).

3.3 Frequency of dogs that were spayed-neutered during 2014–2018

During 2014–2018, about 180 dogs per year were spayed-neutered (57% females, 43% males) (Table 4).
Any model scenario which used 180 dog sterilizations per year (the current rate) was insufficient to control the dog population size (Figure 1). The dog population declined when 550 dogs were sterilized each year and 70% or more were females (Figure 2).

### Discussion

Our study provides new data which better define and quantify the existing dog overpopulation problem on the Galapagos. Our study results show the dog population on Santa Cruz Island has increased by 55% from 2014 to 2018. In addition, study results indicate that current spay-neuter efforts (about 180 dog sterilizations per year...
in the last 5 years; 57% females, 43% males) are not enough to keep the dog population stable (i.e., current baseline of 3,886 dogs in 2018).

The observed HD ratio (4.04:1) (which extrapolates to 3,886 dogs) represents an increase of 55% in the dog population on Santa Cruz Island from 2014 to 2018 (Diaz et al., 2016). One result that supports our interpretation that the dog population increased from 2014 to 2018 is the number of households with ≥1 dogs which increased from 40% in 2014 (Diaz et al., 2016) to 58% in 2018. Another explanation is the annual number of spayed/neutered dogs which decreased by about 40% during 2015–2018, compared to 2014 (Diaz et al., 2016). Education and legislation are two additional, broad factors that can influence dog population growth on the Galapagos. The ABG has an active community education program on responsible pet ownership on the Galapagos, which includes dog sterilization. Our results, however, do not show evidence that such effort has had a significant effect on controlling the dog population during 2014–2018. Furthermore, a current legislation does not require pet owners to sterilize their dogs. Information on the socio-economic aspects (e.g., companionship, home security, other) that can influence pet owners to acquire dogs, to allow dog reproduction, and to accept or reject mandatory dog sterilization can be useful to policy makers to justify a mandatory spay/neuter legislation.

Study results show that current spay/neuter efforts are not enough to keep the dog population stable. Based on 2018 dog demographic data, a previous model using data from 2016 (Diaz et al., 2018) overestimated the growth capacity of the dog population by 17% (4,550 dogs) on Santa Cruz Island, primarily by assuming a higher yearly survival rate. Updated parameters used in this study indicate that 550 surgical dog sterilizations per year (≥70% female dogs) are required to stem the dog population growth rate. Results from the new model are relevant because they can help local policy makers justify financial resources required to support dog population management control strategies.

### Table 4 Frequency of dogs that were spayed-neutered on Santa Cruz Island during 2014–2018a

| Year | Males | Change | Females | Change | Total | Change |
|------|-------|--------|---------|--------|-------|--------|
| 2014 | 109   | Baseline | 175     | Baseline | 284   | Baseline |
| 2015 | 66    | 40% lessb | 72      | 59% lessb | 138   | 52% lessb |
| 2016 | 95    | 13% less  | 85      | 52% less  | 180   | 37% less  |
| 2017 | 58    | 47% less  | 73      | 42% less  | 131   | 54% less  |
| 2018 | 71    | 35% less  | 120     | 31% less  | 191   | 33% less  |

*Source: Galapagos Biosecurity Agency.

bCompared to baseline frequency of dogs that were spayed-neutered on Santa Cruz Island in 2014.

---

**Figure 1** Effect of 180 surgical dog sterilizations per year on dog population size, when the proportion of spayed female dogs is 50–100%. *Blue line = 50% spayed female dogs; red line = 60%; green line = 70%; orange line = 80%; yellow line = 90%; teal line = 100%. Error bars = 95% confidence interval

**Figure 2** Effect of 550 surgical dog sterilizations per year on dog population size, when the proportion of spayed female dogs is 50–100%. *Blue line = 50% spayed female dogs; red line = 60%; green line = 70%; orange line = 80%; yellow line = 90%; teal line = 100%. Error bars = 95% confidence interval
This study has several limitations. First, the proportion of surveyed households was 196/332 (59%), similar to that in September 2016 (237/390 or 60%) (Diaz et al., 2018). A higher proportion of surveyed households (e.g., by including a second visit to the selected block at a different time of day or a different day) could have provided more validity and precision to our study results. However, following advice from the ABG Director’s Office, the period of 16.30 hr to 19.30 hr was considered as the most appropriate time to conduct house-to-house interviews, when family members are back from work or school. In addition, the estimated dog population (i.e., 3,886 dogs) was based on the observed HD ratio (4.04:1) and the most recent human population estimate for Santa Cruz (i.e., 15,701 people based on official records from Ecuador’s Instituto Nacional de Estadística y Censos, 2015). Thus, if the human population was higher in 2018 than that in 2015, the dog population in 2018 reported here is an overestimate. Finally, the dogs’ age reported by dog owners was not verified by examining dogs’ dentition. Limited time and resources to complete the survey, as well as safety concerns (potential risk of dog bites to dog owners or ABG personnel) affected our capacity to verify the age of study dogs. We consider the risk of age group misclassification (<11 months-old; 1–2 years old; 3–14 years-old) in study dogs to be very low or negligible. All dogs ≤11 months old were those reported as being born after September 2017. However, it is possible that one or more dogs that were 24 months old were reported as three-years old or those that were 25 months old were reported as 2-years old. If the age classification was incorrect in several dogs during model initialization, the population’s age structure would correct itself after a few years because of the birth/death rates recorded for the analysis. Overall, our study results support our interpretation that the dog population increased during 2014–2018. We have produced evidence that the observed HD ratio has decreased from 6.14:1 in year 2014 to 4.04:1 in year 2018. In addition, the number of households with ≥1 dogs increased from 40% to 58%. Furthermore, the annual number of dog sterilizations decreased by about 40% during 2015–2018, compared to 2014.

5 | POLICY OPTIONS

Study results justify a revision of the current management action plan to control dog reproduction on Santa Cruz Island, Galapagos. Galapagos policymakers can consider several options designed to mitigate dog overpopulation such as: (a) education on dog overpopulation and responsible dog ownership; (b) a mandatory dog spay/neuter legislation; (c) a certified shelter facility as the only source for adoption of spayed/neuter dogs (instead of residents buying or acquiring intact dogs from dog owners in the community with no supervision); (d) funding to increase the current annual volume of dog sterilizations, and primarily target female dogs; and (e) funding to enhance home security and burglary prevention on Santa Cruz Island.

ACKNOWLEDGEMENTS
This study was funded in part by the (i) Agencia de Regulación y Control de la Bioseguridad y Cuarentena para Galápagos and (ii) the University of Florida’s College of Veterinary Medicine and the Center for Latin American Studies.

CONFLICT OF INTEREST
The authors declare no potential conflict of interest.

AUTHORS’ CONTRIBUTIONS
J.A.H. provided input on conceptualization, methodology, software, formal analysis, writing (original draft, review and editing), supervision, project funding and administration. A.J.Y. provided input on methodology, software, and formal analysis. H.S.W. provided input on methodology. N.T., D.Z. and R.C. performed data collection. V.D. performed supervision and project administration. M.C. performed supervision, project funding and administration. All authors reviewed and approved the manuscript.

DATA ACCESSIBILITY STATEMENT
Research data are available from the corresponding author upon request.

ETHICS STATEMENT
This study received approval from the University of Florida’s Institute of Animal Care and Use Committee (protocol # 201609271).

ORCID
Jorge A. Hernandez https://orcid.org/0000-0002-3096-4762

REFERENCES
Denkinger, J., Guevara, N., Ayala, S., Murillo, J. C., Hirschfeld, M., Montero-Serra, I., ... Trueba, G. (2017). Pup mortality and evidence for pathogen exposure in Galapagos Sea lions (Zalophus wollebaeki) on San Cristobal Island, Galapagos, Ecuador. Journal of Wildlife Diseases, 43, 491–498.
Diaz, M. N., Mendez, G. S., Grijalva, J., Walden, H. S., Cruz, M., Aragon, E., & Hernandez, J. A. (2016). Dog overpopulation and burden of disease exposure to canine distemper virus and other pathogens on Santa Cruz Island, Galapagos. Preventive Veterinary Medicine, 123, 28–137.
Diaz, M. N., Walden, H. S., Yoak, A. J., McIntosh, A., Duque, V., Cruz, M., & Hernandez, J. A. (2018). Dog overpopulation and burden of disease exposure to canine distemper virus and diagnosis of intestinal parasites on Santa Cruz Island, Galapagos 2016. Preventive Veterinary Medicine, 157, 99–104.

Kruuk, H., & Snell, H. (1981). Prey selection by feral dogs from a population of marine iguanas (Amblyrhynchus cristatus). Journal of Applied Ecology, 18, 197–204.

Levy, J. K., Crawford, P. C., Lappin, M. R., Dubovi, E. J., Levy, M. G., Alleman, R., ... Clifford, E. L. (2008). Infectious diseases of dogs and cats on Isabela Island, Galapagos. Journal of Veterinary Internal Medicine, 22, 60–65.

Reponen, S. E. M., Brown, S. K., Barnett, B. D., & Sacks, B. N. (2014). Genetic and morphometric evidence on a Galapagos Island exposes founder effects and diversification in the first-known (truly) feral western dog population. Molecular Ecology, 23, 269–283.

Riofrío-Lazo, M., Arreguín-Sánchez, F., & Páez-Rosas, D. (2017). Population abundance of the endangered Galapagos Sea Lion Zalophus wollebaeki in the southeastern Galapagos archipelago. PLoS One, 12(1), e0168829. https://doi.org/10.1371/journal.pone.0168829

Trillmich, F., Jeglinski, J. W. E., Meise, K., & Piedrahita, P. (2014). The Galapagos Sea lion: Adaptation to spatial and temporal diversity of marine resources within the Archipelago. In J. Denkinger & L. Vinueza (Eds.), The Galapagos marine reserve (pp. 61–70). New York: Springer Science & Business Media.

Yoak, A. J., Reece, J. F., Gehrt, S. D., & Hamilton, I. M. (2016). Optimizing free-roaming dog control programs using agent-based models. Ecological Modelling, 341, 53–61.

SUPPORTING INFORMATION
Additional supporting information may be found online in the Supporting Information section at the end of this article.

How to cite this article: Hernandez JA, Yoak AJ, Walden HS, et al. Dog overpopulation on Santa Cruz Island, Galapagos 2018. Conservation Science and Practice. 2020;2:e201. https://doi.org/10.1111/csp2.201