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Do dog-human bonds influence movements of free-ranging dogs in wilderness?

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ABSTRACT

Domestic dogs have a close and mutualistic relationship with humans. When unconfined, they usually stay close to the owner's home, but some undertake intensive forays in nature with negative impacts on wildlife. Predictors for such problematic dogs in previous research concentrated on dog characteristics and husbandry. Here we additionally explored which aspects of the dog-human bond influenced the movements of free-ranging village dogs in southern Chile. Using an interdisciplinary framework, we assessed the strength of this relationship through (i) attachment behaviours performed during the Strange Situation Procedure (SSP, dog's perception of the relationship) and (ii) the Monash Dog-Owner Relationship Scale questionnaire (MDORS, owner's perception) in 41 dog-owner dyads while remotely monitoring the dogs' movements using GPS tracking (n = 36394 locations). We found that 39 % of dogs had > 5 % of their locations in natural areas, but only three individuals exhibited overnight excursions. Home range size (1.8-4227 ha) and mean distances to the owner's home (0-28.4 km) varied greatly among individuals. Through generalized linear models we identified that dogs had larger home ranges, moved farther away from home or accessed nature more (i.e., they exhibited more intensive forays) when they explored more, greeted their owners intensively, and expressed more passive behaviours in the presence of their owners (SSP). However, the MDORS questionnaire was a poor predictor of home range, distance to home, and access to nature. When considering the dogs' background, older dogs, males, and dogs that got missing more frequently exhibited more intensive forays. Compared to SSP results in confined dogs, we suggest that owners of free-ranging dogs do not play an important role as an attachment figure. We conclude that the dog-owner bond indeed influences roaming behaviour in dogs. This highlights the necessity of wildlife management strategies considering the cultural context. In specific terms, we recommend to foster the knowledge of the importance of bonds between dogs and their owners in educational campaigns on responsible dog ownership, along with biological (age, sex) and behavioural characteristics (exploration, getting missing). That way, awareness campaigns can focus on owners of possible problematic dogs.

1. Introduction

Dogs (*Canis familiaris*) are the first domesticated species by humans (33000 years before present, Wang et al., 2016). This long relationship has led to manifold roles for dogs in human societies, from company to guardian, hunting, search, rescue, or guide dogs (Lord et al., 2016; Arahori et al., 2017). Not only do the roles of dogs in human societies differ, but also their husbandry. In industrialized countries dogs are often in-door family members with highest care and health standards, whereas in other cultures they are often less confined and under lower subsistence conditions (Jackman and Rowan, 2007; MacDonald and Carr, 2017). Yet, dog husbandry not only depends on a country's economic level, but above all - on culture. In a cross-cultural analysis of human-pet dynamics covering 60 societies, Gray and Young (2011) revealed dogs were actually most often used in hunting and least for entertainment, whereas positive treatments such as grooming occurred less than negative interactions (e.g., physical abuse). In most societies, dogs roamed outdoors, next often indoors, and lastly outdoors with people; and they slept equally outside and inside.

During the last decade, the consequences of unrestricted dog movements has gained increased attention in the field of Conservation Biology (Young et al., 2011; Hughes and Macdonald, 2013; Twardek

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et al., 2017). The impacts of free-ranging dogs in natural ecosystems from most to least reported are predation, disturbance, transmission of diseases, competition, and hybridization with wildlife (Doherty et al., 2017). This trend may be increasing as dog populations increase with human populations worldwide, currently reaching 987 million dogs (Gompper, 2014).

Free-ranging dogs are urban, village, rural – with a gradient in dependency on humans – or feral dogs, which are completely wild and independent of human subsidy (Vanak and Gompper, 2009). As stated above, in many regions of the planet, owned dogs are allowed to roam free and they do not refrain from impacting wildlife (Gompper, 2014). Owned dogs may veer away as far as 10–20 km from their homes (Molloy et al., 2017; Pérez et al., 2018) but most stay within their vicinity (< 250 m, Vaniscotte et al., 2011; Sepúlveda et al., 2015). A range of factors can influence the movement of free-ranging dogs, e.g., dog characteristics (Dürr et al., 2017), provision of food (Ruiz-Izaguirre et al., 2015; Molloy et al., 2017), and the presence of owners (Dos Santos et al., 2018). However, to our knowledge the potential effects of dog-owner bonds on dogs' movements have not been addressed.

Dogs have remarkable social skills which allow them to develop a close and mutualistic relationship with humans (Miklósi and Topál, 2013; Payne et al., 2015; Lea and Osthaus, 2018). This bond, or attachment, is defined as "the relatively long-enduring tie in which a partner is important as a unique individual and is interchangeable with none other", where partner is an attachment figure (Ainsworth, 1989:711). According to Bowlby (1969), attachment is applicable to all mammals and involves specific behaviours related to the attachment figure such as maintaining proximity, distress at separation, and attachment figure as a secure base to explore the environment, finding security and comfort in it, if necessary. These behaviours are the result of evolutionary processes, adopted to improve survival by maintaining proximity with their conspecifics, especially with the mother (Bowlby, 1969; Ainsworth, 1989). Importantly, attachment and dependency are different constructs (empirical evidence in Kungl et al., 2019).

The Strange Situation Procedure (SSP) is a method to assess attachment from infants to their mothers by putting them in a stressful situation by meeting a stranger in a new environment (Ainsworth and Bell, 1970). Because dogs develop similar bonds to their owners as those created between infants and mothers during early ontogeny (Miklósi and Topál, 2013), the SSP has been adopted to examine domestic dog bond strength towards owners (Topál et al., 1998) in behavioural assessments in companion dogs (e.g., Rehn et al., 2014), rescue dogs (e.g., Scandurra et al., 2016), working dogs (e.g., Lenkei et al., 2021) and in physiological assessments measuring cortisol reactivity (e.g., Schöberl et al., 2016). Complementary, to assess the owners' perception, the Monash Dog Owner Relationship Scale questionnaire (MDORS, Dwyer et al., 2006) is the most extensively used (review in Payne et al., 2015). This tool follows the theory of social exchange, which defines a relationship as successful when costs and benefits are balanced, or when benefits overcome the costs of the relationship (Emerson, 1976). Following Netting et al. (1987) this theory can also be applied to companion animals. As with the SSP, physiological assessments showed correlations between the questionnaire and the dog's oxytocin and cortisol levels (e.g., Handlin et al., 2012).

Our study aim was to test whether dog-human bonds influence the spatial movements of free-ranging dogs. For our study, we prefer using the term caregiver over owner according to the World Organization of Animal Health, which defines dog ownership as accepting responsibility for the physical and behavioural needs of the dog as well as ensuring not roaming out of control (OIE, 2019). We predicted that dogs with a stronger bond to the caregiver would stay closer to home, similarly to dogs with caregivers who report successful relationships (as defined by Emerson, 1976). Besides the bonds, we also considered dog characteristics and husbandry-related factors from earlier studies and predicted that female (e.g., Vaniscotte et al., 2011; Sparkes et al., 2014; Dürr et al., 2017; but see Van Kesteren et al., 2013), older (Pérez et al., 2018), adequately fed (Ruiz-Izaguirre et al., 2015), and sterile dogs (e.g., Sparkes et al., 2014; Dürr et al., 2017; Molloy et al., 2017; but see Garde et al., 2016) roam less. We tested this through: (i) remote monitoring of dog movements; (ii) questionnaires on the dog's background; (iii) assessment of the dog-caregiver bond from the dog's perception; and (iv) from the caregiver's perception. This socio-ecological framework was tested on 41 free-ranging, mixed-breed village dogs with close access to pristine sub-Antarctic ecosystems in southern Chile. This is a pioneer study that allows researchers to predict which aspects of the dog-caregiver bond influence a dog's willingness to venture into natural settings, thus providing a novel platform for dog management strategies for biological conservation.

2. Methods

2.1. Ethical note

We fitted 41 dogs with light-weight GPS data-loggers (I-gotU GT-600, Mobile Action, Taiwan, 37 g). The device was sealed in weatherproof bags, placed inside hand-made leather cases, and attached to their own or a commercial dog collar with safety tapes. We did not weigh the dogs to avoid stress, but the approximate percent body weight of the device in its bag was 0.19−0.44 % for large-sized and medium-sized animals, respectively. Dogs were tracked for three weeks (20.5 ± 5.3 days, range = 6–35 days) from December to March either during summer one (2016–2017) or summer two (2018–2019). All devices were removed from all dogs. No dog was forced to enter the room to perform the SSP. Only one dog refused to enter and was excluded from the analysis. All caregivers signed a consent form with information on the project aims, absence of risks, access to the results, and guaranteed anonymity. At the end of the study, participation was compensated with an economic incentive (CLP $10000/US $12.50). The Scientific Ethical Committee of the University of Magallanes certified the ethical approval of the study (N°001/CEC/2016, N°003/CEC/2018).

2.2. Study area

Our study was conducted on Navarino Island, southern Chile (Fig. 1), with Puerto Williams as the only major settlement (74.5 ha, 2100 inhabitants). Each summer, the pristine character of Navarino attracts an increasing number of tourists interested in trekking. On Navarino Island, 30.6 % of owned dogs roam free (Schüttler et al., 2018) and the majority of free-ranging dogs in this small town are dogs with a clearly referable caregiver, following a photographic four-season-census (Schüttler et al. unpublished data) and a classification of dogs photographed in camera-traps outside the town from which 74 % of 26 individuals were identified as owned (Contardo et al., 2020). We also know free-ranging dogs on Navarino Island preferred peatbog over forest and shrubland and that there is evidence of a feral population of dogs (Contardo et al., 2020). As the island is free of native, terrestrial predators (Anderson et al., 2006), dogs can have significant impacts on the native fauna, particularly on birds such as geese or ducks (Schüttler et al., 2009) and southernmost guanacos (*Lama guanicoe,* González, 2010). Moreover, dogs are involved in conflicts with local farmers as they often attack livestock (Schüttler et al., 2018).

2.3. Subjects

We approached only adult dog caregivers (≥ 18 years) in Puerto Williams whose dogs ranged free, were adult (≥ 1 year), and lived together with their caregivers for ≥ 6 months (Rehn et al., 2014). The majority of subject dogs (81 %) originated from Navarino Island, which lacks an animal shelter. Most dogs (76 %) were also obtained as puppies or adolescents (available information for 29 dogs); hence, they were able to develop their bond with their caregivers from an early age onwards. All dogs had either access to the caregiver's house and/or to the

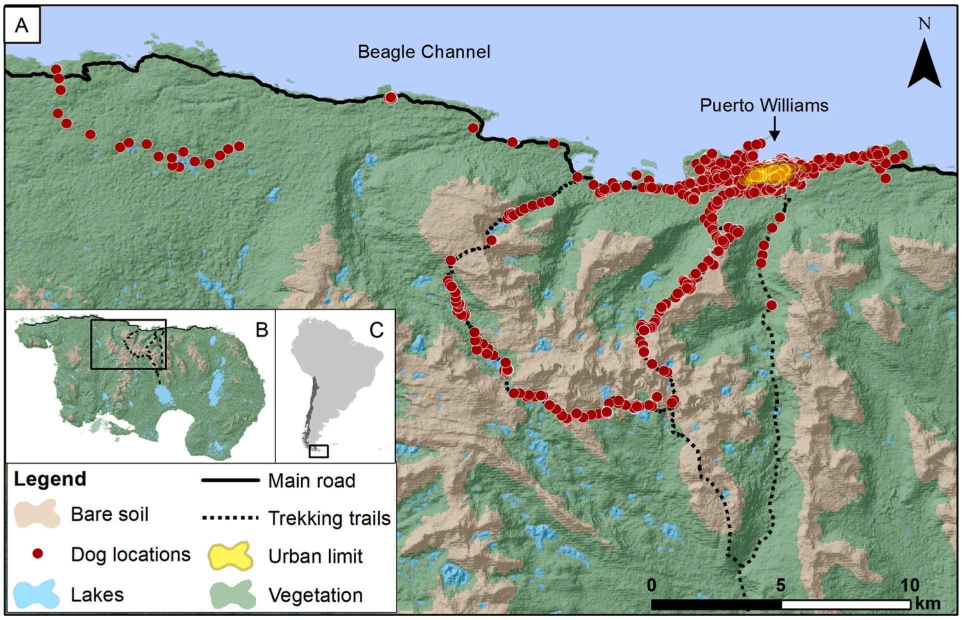

Fig. 1. Study area where we assessed if dog-caregiver bonds influenced spatial movements of free-ranging dogs. A: Dog movement data of 41 dogs (n = 36394 locations in 10-min intervals) during summer (2016–2019); B: Navarino Island; C: southern Chile, South America.

caregiver's yard. To avoid data dependency, we only selected one dog per caregiver, the one with presumable forays away from home. We contacted 44 dog caregivers, which represented approximately half of the extrapolated free-ranging dog population in Puerto Williams (estimated n = 84, Schüttler et al., 2018); three contacted caregivers refused to participate. A health check (general aspect, lymph nodes, skin, mucous membranes, body condition, heart rate) assured that the selected dogs were in adequate condition to participate in the study. The body condition was based on a 5-point score, with 5 meaning obese (e.g., McGreevy et al., 2005). Once finished, digital video material and GPS positions of the dogs were handed to each caregiver.

2.4. Dog background

Based on previous research in the study area (Schüttler et al., 2018), we created a questionnaire with 24 closed and open questions (Supplementary material S1) about dog characteristics, husbandry, dog-caregiver interaction, dog-wildlife interaction, and basic personal

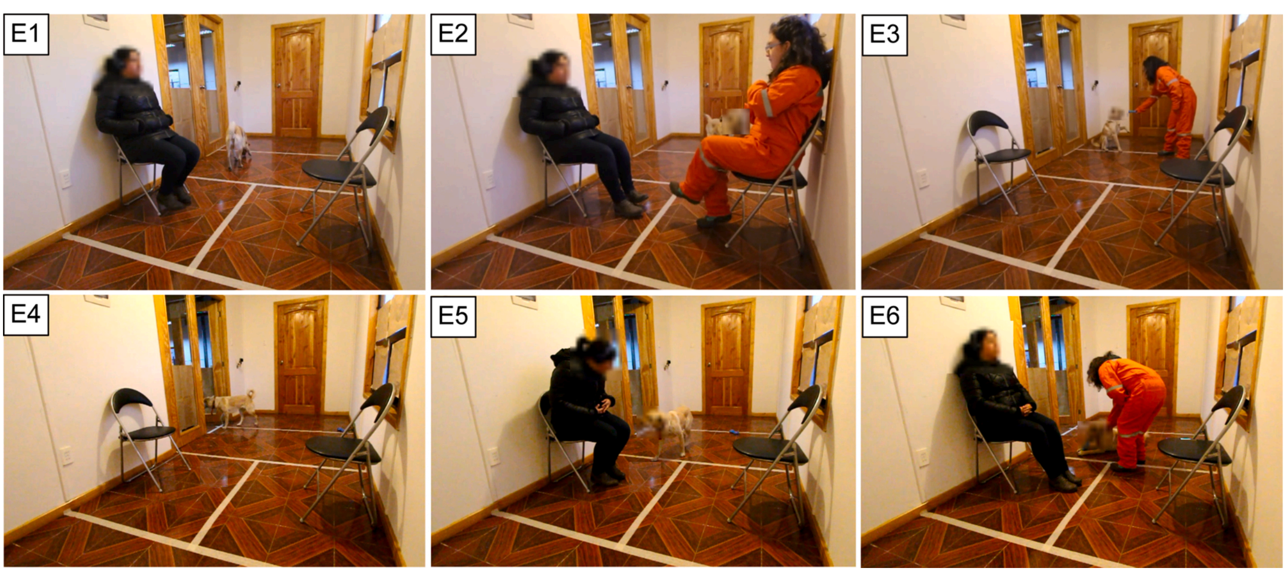

Fig. 2. Description of the SSP adapted (time lapsus) from Rehn et al. (2014). In the background of each image is the main door and on the left side the door to room 2. C = caregiver, D = dog, E = episodes, S = stranger. C and S always enter and leave through the main door. E1 (D+C, min 1–3): C sits quietly in chair and ignores dog. D is free to explore room 1; E2 (C+D+S, min 4–6): S enters room 1 and sits quietly for 1 min. During min 5, she starts talking with C. When min 6 starts, S sits on floor and initiates play with D using toy (one toy at a time). S returns to chair if D does not want to play. C quietly leaves test area 20 s before end of episode; E3 (D+S, min 7–9): S continues/initiates play with D and returns to chair after 45 s if D does not want to play. S opens door to room 2 and leaves test area 20 s before end of episode; E4 (D, min 10–12): D remains alone and can explore rooms 1 and 2; E5 (C+D, min 13–15): C enters room 1, waits for 7 s and greets D for 10 s (without specific instructions of how to greet). Then, C sits on chair and ignores D; E6 (D+S, also C at beginning, min 16–18) S enters room 1, waits for 7 s and greets D for 10 s (S first greets D verbally and starts physical contact only if D shows signs of acceptance). Then, S sits on chair and ignores D. C leaves the test area when S stopped greeting D.

owner information (gender, age, residence time on Navarino Island, education level, first time dog caregiver).

2.5. Dog movements

All GPS devices recorded locations in 10-min intervals only when movement was detected. The device error was evaluated by performing a series of mobile and static tests, following Cargnelutti et al. (2007) and Camp et al. (2016). According to those tests, we first excluded locations with abnormal elevation parameters (i.e., 9.1 %, n = 3754/41519). Second, we asked caregivers to report excursions with their dog outside town. The locations of those accompanied dogs were then removed (i.e., 3.6 %, n = 1371/37765), yielding a total of 36394 reliable locations.

2.6. Dog-caregiver bonds

During January and April 2018, we tested dog attachment behaviour towards the caregiver by performing the SSP (Topál et al., 1998). We carried out and filmed six 3-min experimental episodes (Fig. 2), adding a second room to evaluate exploration behaviours (e.g., Palmer and Custance, 2008; Rehn et al., 2014, sketch in Supplementary material S2). A woman without previous contact with the dogs performed as the stranger in all tests. Throughout the procedure caregivers were instructed through headphones. This included to not interact with their dogs even if the dog approached the caregiver. After each session, we disinfected the test area and the stranger used a fresh overall.

The videos were analysed using instantaneous (5 s intervals) and continuous sampling, facilitated by the software BORIS (Friard and Gamba, 2016). We classified behaviours into 20 categories following the ethograms in Palmer and Custance (2008) and Rehn et al. (2013) (Supplementary material S3, revised by a veterinarian) and summarized them as the proportion of time/episode and time/min during reunion (Rehn et al., 2014); apart from greeting, which was classified according to its intensity (Palmer and Custance, 2008). In room 2 we only recorded the total time the dog spent in it, not behaviours. Only five individuals played (3.9 % social play and 2.1 % independent play of overall possible sample points); therefore, play behaviour was excluded from analyses.

We evaluated caregivers' bonds with their dogs by asking 27 closed questions from the MDORS questionnaire (Dwyer et al., 2006), grouped into three subscales: (i) dog-caregiver interaction, (ii) emotional closeness, and (iii) perceived cost; higher scores of the 5-point Likert scales represented a stronger bond (Supplementary material S4). We used the Mexican Spanish translation of González-Ramírez et al. (2017) and adapted it to Chilean Spanish. Internal consistency of each subscale was calculated using Cronbach's alpha.

2.7. Statistical analyses

We used generalized linear modelling (Nelder and Wedderburn, 1972) to investigate which variables (n = 16, Table 1) from the dog's background and the dog-caregiver bonds best predicted the spatial movements of dogs. To describe the movement of each dog, we used three different response variables: home range size, mean distance to the caregiver's home, and whether the dog entered natural areas (Table 1). Thus, those dogs with high values in these categories exhibited more intensive forays in nature, possibly interacting with wildlife. We applied Gaussian error structure (linear model) for home range and distance and binomial error structure with logit link for whether the dog entered natural areas.

Home range size (HOME) was calculated by autocorrelated kernel density estimation for the monitoring period of each dog after fitting continuous-time stochastic process models using the ctmm package (Calabrese et al., 2016) in program R (R Core Team, 2019). In ctmm, we also confirmed that individuals were range residents by visually inspecting whether the semi-variance in the variograms reached an asymptote. We used the 95 % home range area for all dogs but three (n = 38), as these dogs had multiple overnight excursions outside of town. For those dogs, we used the low estimate (i.e., low value of the 95 % confidence intervals of the 95 % home range area) to adjust for overestimation of home range size. We excluded physical barriers from the analysis. For this, we selected the farthest dog location in the Beagle Channel (i.e., 236.8 m from the coastline) and added the GPS error (6.2 m, mobile test), deleting areas beyond 243 m from the coast. The mean distance (DISTANCE) to the caregiver's home was the mean linear distance from all dog's locations to its home over the dog's sampling period. Finally, we denoted a 1 when a dog entered natural areas in > 5 % of all recorded locations (NATURE), but a 0 otherwise (stayed in urban areas or left them in ≤ 5 % of all recorded locations). Thus, we ensured a more equal distribution of the data. Locations, home ranges, and distances to caregivers' homes were projected in WGS 1984 UTM zone 19S and mapped in ArcMap 10.4 (ESRI, Redlands, USA).

We selected explanatory variables from the dog's background, SSP, and MDORS results (Table 1). From the questionnaire on the dog's background, we selected the dog's age (AGE), sex (SEX), food provisioned (FOOD), and whether it was sterilized (STERILE) due to their importance in dog-wildlife interactions. We also included access to the

Table 1
Overview of response and explanatory variables used in modelling the movement of free-ranging dogs in southern Chile.

Assessment	Variable	Description
GPS MONITORING	DISTANCE (R)	Mean linear distance to caregiver's home (km) during summer
	HOME (R)	Home range area (ha) for each dog in one summer season
	NATURE (R)	0 = dogs with ≤ 5 % locations in natural areas 1 = dogs with > 5 % locations in natural areas
BACKGROUND	ACCESS (E)	Access inside to caregiver's house: never, 1–2 times a week, 3–5 times a week, daily
	AGE (E)	Continuous integers (years)
	FOOD (E)	Feeding mainly by: commercial dog food and/or meat, leftovers, mix of above
	MISSING (E)	Continuous integers (i.e., 24 h, days missing during last year)
	SEX (E)	Male/Female
	STERILE (E)	Yes/No
SSP	C/S ZONE (E)	Change in dog's position in caregiver's vs. stranger's presence (i.e., caregiver's zone or stranger's zone, range = −0.25–0.80)
	DOOR (E)	Change in dog's position in proximity to the door in caregiver's versus stranger's presence (range = −0.8–0.4)
	GREETING (E)	Change in intensity of greeting in caregiver's vs. stranger's greeting (low to high: 0–3 on 0.5-point scale)
	PASSIVE (E)	Change in passive behaviour (i.e., dog is sitting, lying, or standing without any obvious attention to physical or social environment) in caregiver's vs. stranger's presence (range = −0.6–0.7)
	ROOM 2 (E)	Change in access to room 2 in stranger's presence vs. dog alone (range = −0.8–0.2)
	TAIL (E)	Change in tail wagging during caregiver's vs. stranger's greeting (range = −0.5–0.8)
MDORS	COST (E)	Low to high level of perceived cost of caring for a dog (range = 30–45)
	EMOTION (E)	Low to high level of emotional closeness perceived by caregiver (range = 28–49)
	INTERACTION (E)	Low to high level of dog-caregiver interaction (range = 15–33)

Positive ranges in the SSP represent values of the dog's behaviour in company of the caregiver, while negative values are in company of the stranger, except for ROOM 2. Here negative values indicate the dog is alone and positive values with the stranger. Explanatory variables are ordered alphabetically. Variable type R = Response, E = Explanatory.

caregiver's house (ACCESS) and the reported number of days the dog had been missing (MISSING). In SSP, we evaluated significant differences between episodes with the caregiver present versus the stranger present and the dog alone versus the stranger present, using Wilcoxon signed rank tests. The most relevant behaviours among those with significant differences were identified via principal component analysis (PCA) for each of the six episodes and greeting minutes, among which we created five change behaviour variables and one greeting intensity variable (similar to Rehn et al., 2014). Finally, we used the score of each subscale of the MDORS questionnaire as explanatory variables (INTERACTION, EMOTION, COST).

We evaluated collinearity for numerical variables by Spearman's correlations excluding those variables with $r_s > |0.6|$. For categorical predictors we used Chi-square and Fisher's exact tests with significance levels of $P \leq 0.05$. Two-way relationships were found for ACCESS and STERILE ($X^2_1 = 4.95$, $P = 0.03$; Fisher's exact test, $P = 0.02$, STERILE retained), for TAIL and GREETING ($r_s = 0.64$, $N = 39$, $P < 0.01$, GREETING retained) and INTERACTION and EMOTION ($r_s = 0.65$, $N = 40$, $P < 0.01$, EMOTION retained). For each model set, we did not consider cases that contained NAs in the explanatory variables. We log-transformed DISTANCE and HOME due to their large span, but report back-transformed values for estimated coefficients and standard errors (Cade, 2015). Explanatory variables were measured on different scales and therefore were z-transformed.

Since we had 13 potential explanatory variables with only 41 observations, to avoid overfitting (Mundry, 2014), we first built three separate model sets: (i) dog background questionnaire (BACKGROUND), (ii) dog's perspective of the bond (SSP), and (iii) caregiver's perspective (MDORS). We compared all potential combinations of explanatory parameters using Akaike's information criterion corrected for small sample size (AIC_c) (Burnham and Anderson, 2002). We then built a final model set (iv) OVERALL using the variables from the best model ($\Delta AIC_c = 0$) of the previous model sets. We analysed each of the three response variables separately.

For all models, variance inflation factors were < 5 and no obvious deviations were found by visual inspection of normality and homoscedasticity in the residuals' plots for the linear models (Supplementary material S5). For each model set, the significance of the full model was evaluated through comparison with the null model by Likelihood Ratio Tests (LRT). All full models were different from the null model, unless otherwise stated. The relative importance of parameters within each model was calculated by adding the weights (ωAIC_c) for each explanatory variable. All statistical analyses were carried out in program R (R Core Team, 2019), using the packages MuMIn (Barton, 2019) and AICcmodavg (Mazerolle, 2019).

3. Results

Caregivers had a mean age of 41.5 years (range = 18-89), 54.5 % were female, with a residence time of 20.4 years (0.5-48) and different levels of education: primary (9.7 %), secondary (48.8 %), and tertiary (41.5 %); only two participants were first time dog caregivers.

3.1. Dog background

The participating dogs had a mean age of 5 (± 2.8) years, were slightly skewed towards males (63.4 %), and received a moderate to high level of husbandry with 56.1 % given commercial dog food, 70.7 % sterilized, and 63.4 % having access to the caregiver's house. Only one dog was underweight (i.e., mean body condition score < 2.5). Over half (56.1 %) were 24-h free-ranging, whereas 46.3 % had gone missing for ≥ 1 day, during a mean period of 4.9 (±3.1) days (Table 2). The caregivers' responses also indicated that wildlife interaction existed: prey categories brought home were native birds (41.7 % of 12 records) and invasive muskrat (*Ondatra zibethicus*, 33.3 %); harassed animals included livestock (51.5 % of 66 records) and native birds (18.2 %).

3.2. Dog movement

We collected 36394 locations from 41 unaccompanied, free-ranging dogs with a mean of 887.7 ± 281.7 (median = 868.0, range = 298-1517) locations per dog. The mean home range size of all dogs was 310.4 ± 1016.7 ha (19.2, 1.7-4227), with a mean linear distance to the caregiver's home of 0.3 ± 1.3 km (0.04, 0–28.4). Dogs entered natural areas every 4.4 ± 5.4 days (2.1, 0-22); 8.5 % of locations were in natural areas and 16 dogs (39 %) had > 5 % of their locations outside the urban area. The majority of dogs (n = 38) stayed within 0.1 ± 0.3 km of the caregiver's home and had only 7 % of their locations in natural areas (range = 0–58.5 %); three dogs exhibited multiple overnight excursions with 22.1 % of their locations in natural areas (13.2–38.6 %).

3.3. Dog-caregiver bonds

In summary, dogs preferred the caregivers over the stranger's presence in the SSP (Fig. 3), i.e., dogs showed significantly more proximity-seeking behaviours, secure-base effects behaviours, and greeting behaviours (ethogram in Supplementary material S3) in the presence of their caretakers versus the presence of the stranger (P < 0.001 for all Wilcoxon signed rank tests of behavioural comparisons between episodes with caretakers versus stranger, Supplementary material S6). All dogs accessed room 2, almost exclusively in the absence of their caregivers and more often when being alone than with the stranger. After performing Wilcoxon tests (Supplementary material S6) and PCA we selected five change behaviour variables (Fig. 3).

Cronbach's α was 0.37 for the interaction subscale of MDORS, 0.75 for emotional closeness, and 0.74 for perceived costs. Lacking internal consistency, we excluded interaction from modelling. The mean scores of each question, subscale, and total score for the 40 questionnaires are detailed in Supplementary material S4.

3.4. Predictors of dog movements

When considering the dogs' background, dogs exhibited larger home ranges when they had been missing for more days ($\omega AIC_c = 0.95$) and

Table 2
Summary of information on the background of 41 free-ranging dogs in southern Chile.

Dog information	
Demographic data	
Sex ratio (male: female)	1.7: 1
Mean dog age (years) (SD, range)	5 (2.8, 1–11)
Number of large/medium-sized dogs	31/10
Reproductive control	
Sterilized (%)	70.7
Number of offspring in previous year	6 (1 dog)
Health	
Vaccinated against rabies (%)	26.8
Treated for parasites (%)	34.1
Food provisioning	
Commercial food and/or meat (%)	56.1
Leftovers (%)	7.3
Mix of above (%)	36.6
Dogs fed in more than one household (%)	52.2
Mean body condition score (SD, range)	3.3 (0.7, 2–5)
Dog movement	
Unconfined dogs during day or night (%)	43.9
Unconfined during 24 h (%)	56.1
Dogs missing for ≥ 1 day (%)	46.3
Mean number of days gone missing (SD, range)	4.9 (3.1, 1–14)
Dog-caregiver interaction	
Mean daily dog-caregiver interaction (h) (SD, range)	4.5 (4.0, 0.1–16)
Access to caregiver's house (%)	63.4
Dog-animal interaction	
Dogs having brought home prey (%)	24.4
Dogs harassing animals (%)	80.5

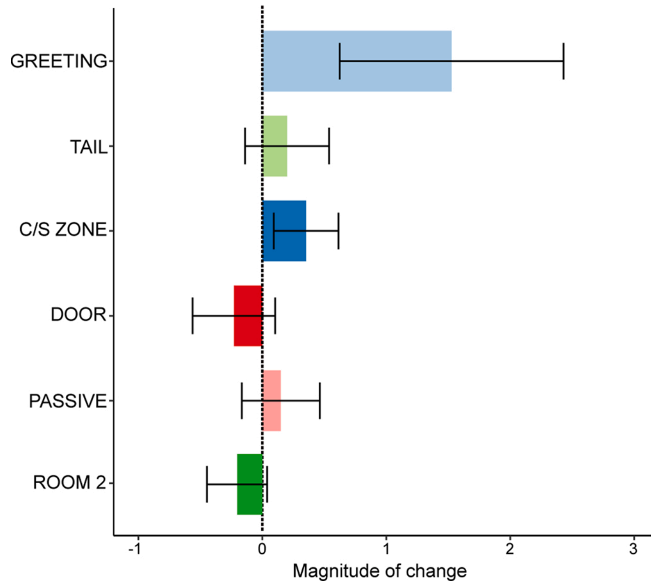

Fig. 3. Magnitude of change in behaviours (mean proportion of time and intensity for GREETING, respectively, ± standard deviation) for dogs (n = 39) during the SSP in southern Chile. Differences considered comparisons between: (i) greeting behaviours: GREETING = greeting intensity (min 13 vs. 16); TAIL = tail wagging during greeting (min 13 vs. 16); (ii) proximity-seeking behaviours: C/S ZONE = dog's position during greeting (i.e., proximity to caregiver or stranger, min 13 vs. 16); DOOR = dog's position in proximity to the door (episode 1 + 5 vs. 3 + 6); and (iii) secure-base effects behaviours: PASSIVE = passive behaviour (episode 5 vs. 6); ROOM 2 = access to room 2 (episode 6 vs. 4). The X-axis indicates the presence of the stranger (negative) vs. caregiver (positive) and of the dog alone (negative) vs. stranger (positive) for ROOM 2, respectively.

when older ($\omega AIC_c = 0.53$; model set BACKGROUND). With regard to the dog-caregiver attachment, dogs that explored room 2 longer when they were alone ($\omega AIC_c = 0.94$) and with a higher greeting intensity towards their caregiver ($\omega AIC_c = 0.59$) had larger home ranges (model set SSP). When considering the caregiver's perception of the relationship, the full model was not significantly different from the null model (LRT, $F_{MDORS} = 0.71$, P = 0.47; model set MDORS). Combining the best predictors of the three model sets in an overall model set, the best model included dogs that explored room 2 longer ($\omega AIC_c = 0.90$) and had been missing for several days ($\omega AIC_c = 0.86$).

Dogs missing for more days ($\omega AIC_c = 0.89$) and older dogs ($\omega AIC_c = 0.79$) exhibited larger mean distances to the caregiver's home (model set BACKGROUND). Again, dogs that explored room 2 longer when alone ($\omega AIC_c = 0.77$) and those that greeted their caregivers more intensively ($\omega AIC_c = 0.66$) went farther from home, but also dogs exhibiting more passive behaviours ($\omega AIC_c = 0.53$; model set SSP). However, in this model set the full model was only marginally significantly different from the null model (LRT, $F_{SSP} = 2.4$, P = 0.06). Again, the full model in model set MDORS was not significantly different from the null model (LRT, $F_{MDORS} = 0.70$, P = 0.50). As for home range, the best model of the overall model set revealed longer exploration of room 2 ($\omega AIC_c = 0.72$) and missing dogs ($\omega AIC_c = 0.69$) as important predictors, but also dogs exhibiting more passive behaviours ($\omega AIC_c = 0.55$).

Consistent with the former models, dogs missing for more days tended to frequent natural areas more than dogs missing less days ($\omega AIC_c = 0.83$), but also males ($\omega AIC_c = 0.71$) did so. Dogs with a longer exploration of room 2 ($\omega AIC_c = 0.97$, model set SSP) were also located more frequently in natural than urban areas. Note that the full model was only significantly different from the null model at the alpha level of 0.1 (LRT, $Deviance_{BACKGROUND} = 1.96$, P = 0.08). Again, the full model in model set MDORS was not significantly different from the null model (LRT, $Deviance_{MDORS} = -1.71$, P = 0.42). In the overall model set, dogs exploring room 2 longer ($\omega AIC_c = 0.94$), male dogs ($\omega AIC_c = 0.75$), and missing dogs ($\omega AIC_c = 0.68$) were the most important predictor variables. See Table 3 for an overview on all parameter estimates, weights, and p-values of all model sets; Fig. 4 for predictors from the best model for each model set.

4. Discussion

Free-ranging dogs are an increasing threat to wildlife globally. In Latin America, owners often allow their dogs to roam (Gompper, 2014; Sepúlveda et al., 2015; Dos Santos et al., 2018). Therefore, it is essential to better understand why some dogs roam farther than others. For the first time, this interdisciplinary study brings together which aspects of the dog-caregiver bond predict how dogs move on forays away from home. Indeed, in this study 98 % (n = 40/41 dogs) accessed nature unaccompanied, whereas 44 % entered nature in company of their caregivers. This indicates that free-ranging dogs foray in nature and possibly interact with wildlife, as also indicated by our questionnaire data on harassment and prey brought home. The median home range size was 19 ha and dogs stayed within 300 m of the caregiver's home, similar to other studies in Chile (Sepúlveda et al., 2015; Pérez et al., 2018) and elsewhere (Vaniscotte et al., 2011; Ruiz-Izaguirre et al., 2015). However, three dogs behaved completely different. They exhibited extensive excursions into natural habitats (on average 22 % of their locations, some on trekking trails) with distances away from home of up to 28 km and home ranges over 4227 ha (or 6170 ha 95 % Minimum Convex Polygon (MCP); 8766 ha 100 % MCP), surpassing the records reported by previous studies (Meek, 1999: 140-2450 ha 100 % MCP; Pérez et al., 2018: 60–2100 ha 95 % MCP). This indicates that some dogs may be more problematic for wildlife and highlights that even dogs detected at very large distances from any urban settlement may be owned.

When investigating the dog's perception of the dog-caregiver bond (SSP), we found that dogs with higher levels of exploration behaviours had larger home ranges, moved farther away from home, and accessed natural habitats more than dogs with lower exploration behaviours; i.e., they exhibited more intensive forays. All dogs explored room 2 and according to the PCA, dogs explored room 2 more during isolation episodes and in the presence of the stranger, not when the caregiver was present. In studies incorporating a second room (Palmer and Custance, 2008; Rehn et al., 2014), dogs explored room 2 in company with their owners and only few individuals even entered the room. Compared to confined dogs, we suggest that caregivers of free-ranging dogs do not play an important role as secure bases. This might be due to less positive interactions between caretakers and their dogs in comparison to confined dogs. The development of positive-human animal relationships requires repeated occasions of positive interactions such as playing, stroking, or talking (review on dogs, Pop et al., 2014), although further research is needed concerning the type, length, and frequency of the interaction (review on animals, Rault et al., 2020). The fact that dogs with higher levels of exploration had more intensive forays might indicate that attachment in those dogs is not strong. Further, exploration behaviours might be exhibited in a more original, non-domestic context, i.e., search for resources or marking territory (Cafazzo et al., 2012; Dos Santos et al., 2018). Although the SSP is a widely used assessment to study attachment in dogs, future research on free-ranging dogs also might consider alternative approaches, such as manipulative tasks in the presence or absence of caregivers (Horn et al., 2013) or shifting the experimental setting to the caregiver's homes (Wedl et al., 2010). Rehn and Keeling (2016) also suggest taking into account individual dog attachment styles and caregiver strategies.

Unfortunately, we could not analyse the sister behaviour of exploration, play, as it occurred infrequently (upon invitation only five dogs marginally played with the stranger). The fact that our participating dogs did not play much could be a result of free-ranging status. When comparing object manipulation between three groups of dogs with

Table 3
Estimates of all predictors of free-ranging dog movement in southern Chile.

Model set	Predictors	HOME				DISTANCE				NATURE			
		E	SE	P	$\sum(\omega AIC_c)$	E	SE	P	$\sum(\omega AIC_c)$	E	SE	P	$\sum(\omega AIC_c)$
BACKGROUND	AGE	15.31	11.08	0.18	**0.53**	13.57	6.03	0.04	**0.79**	0.07	1.14	0.62	0.28
	FOOD LEFTOVERS	−37.10	203.55	0.68	0.30	−37.64	85.70	0.45	0.21	1.11	1.56	0.48	0.14
	MIXED FOOD	124.70	82.66	0.19		30.90	39.91	0.42		0.81	0.83	0.33	
	MISSING	23.70	7.87	0.01	**0.95**	11.52	4.31	0.01	**0.89**	0.27	0.13	0.04	**0.83**
	SEX M	36.60	81.76	0.61	0.26	33.49	39.52	0.39	0.39	1.86	0.97	0.06	**0.71**
	STERILE YES	7.21	95.14	0.92	0.21	−23.36	45.16	0.48	0.33	0.26	0.93	0.77	0.24
SSP	C/S ZONE	−58.45	194.0	0.42	0.28	−33.84	85.82	0.51	0.28	0.53	1.73	0.76	0.26
	DOOR	22.44	140.34	0.82	0.23	22.99	65.52	0.68	0.25	0.66	1.42	0.64	0.23
	GREETING	77.00	38.68	0.09	**0.59**	42.93	20.67	0.07	**0.66**	0.52	0.61	0.40	0.30
	PASSIVE	60.03	138.07	0.59	0.27	110.56	64.61	0.14	**0.53**	−0.94	1.41	0.51	0.25
	ROOM 2	−94.42	206.82	0.01	**0.94**	−75.61	90.45	0.04	**0.77**	−5.52	2.31	0.02	**0.97**
MDORS	COST	3.01	6.43	0.64	0.24	2.68	3.61	0.46	0.27	0.01	0.02	0.55	0.27
	EMOTION	−6.08	5.25	0.23	0.39	−3.03	2.96	0.30	0.33	−0.02	0.02	0.23	0.29
OVERALL	AGE	8.87	9.02	0.33	0.30	7.53	5.24	0.16	0.43	–	–	–	–
	GREETING	30.67	30.58	0.32	0.34	21.16	17.02	0.23	0.45	–	–	–	–
	MISSING	16.45	6.84	0.03	**0.86**	7.80	3.95	0.06	**0.69**	0.23	0.13	0.08	**0.68**
	PASSIVE	–	–	–	–	126.37	59.22	0.09	**0.55**	–	–	–	–
	ROOM 2	−91.71	161.00	0.01	**0.90**	−74.04	81.71	0.03	**0.72**	−5.70	2.56	0.03	**0.94**
	SEX	–	–	–	–	–	–	–	–	2.20	1.15	0.06	**0.75**

Predictors were derived from the dog's background (Model set BACKGROUND, n = 39), the dog attachment behaviour towards the caregiver (Model set SSP, n = 39), and the caregiver's perception on his/her relationship with his/her dog (Model set MDORS, n = 40). A final model set (OVERALL) used predictors of the best models from the previous three model sets. We tested for three response variables each: 95 % Autocorrelated Kernel Density Estimation (AKDE) home range (HOME)*, mean distance to caregiver's home (DISTANCE), and entered natural areas (NATURE). E = Estimate, SE = Standard error, P = P-value, $\sum(\omega AIC_c)$ = summed AIC_c weight; variable descriptions are in Table 1. The full model selection containing models with $\Delta AIC_c < 2$ is provided in Supplementary material S7. Predictors' weights of the best model are highlighted in bold. * For three dogs with multiple overnight excursions we used the lower value of the 95 % CI of the 95 % AKDE home range.

different life experiences, free-ranging, pet, and captive dogs, Lazzaroni et al. (2019) found that free-ranging dogs where less persistent, possibly due to less socially guided interaction with objects. In a similar vein, free-ranging dogs responded less to human attentional states in a gazing experiment than pet or captive dogs (Brubaker et al., 2019). In consequence, how dogs behave towards humans apparently depends on their life experiences with wider implications for their behaviour outside the home.

Dogs with larger home ranges and roaming distances to their homes also greeted their caregivers more intensively than the stranger (see also Mariti et al., 2013; Schöberl et al., 2016). Following Bowlby (1969), the evolutive explanation of a greeting is the re-establishment of bonds after reunion with the attachment figure; in social mammals, greeting ceremonies are performed to reconciliate among pack members (Smith et al., 2011). In this sense, dogs spending more time away from their homes might need to express their bond with their caregiver more than dogs staying at or near home most of their time.

Lastly, dogs that went farther from their homes, often sat, laid, or stood around (passive behaviours) in the presence of their caregivers. In the literature, passive behaviours are controversially interpreted; Prato-Previde et al. (2003) for example suggested that they are related to secure base behaviours, whereas Mongillo et al. (2013) believe that they rather actively suppress behavioural signs or emotional distress (Topál et al., 1998). Therefore, we abstain from interpreting passive behaviours in our study and see further research need here. To better understand which behaviours are dominant in free-ranging dogs versus confined dogs, future research could compare both dog categories in the same experimental setting.

Considering the dog-caregiver relationship from the caregiver's perception (MDORS), all subscales were poor predictors of dog movements. There might be a trend in dogs with caregivers reporting lower scores of emotional closeness to move farther from home, but this needs further investigation. Additionally, the MDORS has been developed (Dwyer et al., 2006) for and mostly used in industrialized countries (Mariti et al., 2013; Rehn et al., 2014; Schöberl et al., 2016). Therefore, questions might not match Latin American and/or free-ranging dog culture. For example, if dogs are mainly kept in the streets, they likely will not be taken to visit people and kissing free-ranging dogs might be seen as unhygienic. It is therefore important to develop instruments adjusted to dog cultures and even more – to improve our understanding on how deep cultures influence dog-owner relationships and husbandry. This will answer the question whether measures for responsible pet ownership (e.g., indoor-keeping) are a universal tool.

In contrast to the dog-caregiver bond, the influence of dog characteristics and husbandry on free movements have been addressed by various studies during the last decade. Here, we found that dogs missing for several days, older, and male dogs exhibited more intensive forays. Asking caregivers about how often their dogs disappear thus seems to be a reliable predictor to identify dogs with more access to wilderness. The fact that caregivers did not try to hide this information from the interviewer (e.g., to appear as a responsible pet owner, social desirability bias, Maccoby and Maccoby, 1954) is also an indicator that information in other sensitive questions (e.g., prey brought home, diet) is probably not influenced by this type of bias. Following most caregivers, their dogs got missing because they followed other persons or tourists. Indeed, two dogs were tracked on trekking trails and dogs were also frequently sighted on trails (Schüttler et al., 2018). In this sense, tourism can have a negative influence on conservation if norms restricting the access of dogs on trails are not implemented (Bessa et al., 2019). Those norms should consider that dogs are highly social animals (Marshall-Pescini and Kaminski, 2014) that form bonds with other dogs and humans (Cimarelli et al., 2019); even unowned animals preferred being groomed by a stranger over food (Bhattacharjee et al., 2017).

Older and male dogs also forayed more intensively. Older dogs tend to show more aggressive behaviours (Chopik and Weaver, 2019) standing for territory defence, food resource acquisition, and reproductive opportunities (Lockwood, 2017) – all aspects require roaming from home (but see Pérez et al., 2018). Also, male dogs in this study had larger home ranges (e.g., Sparkes et al., 2014; Dürr et al., 2017; Molloy et al., 2017). According to Scandurra et al. (2018:1) behavioural differences in dogs' sex are "mainly rooted in their biological and evolutionary heritage, remaining unchanged despite artificial selection". Therefore, biological characteristics of dogs should be included in educational campaigns on responsible dog ownership.

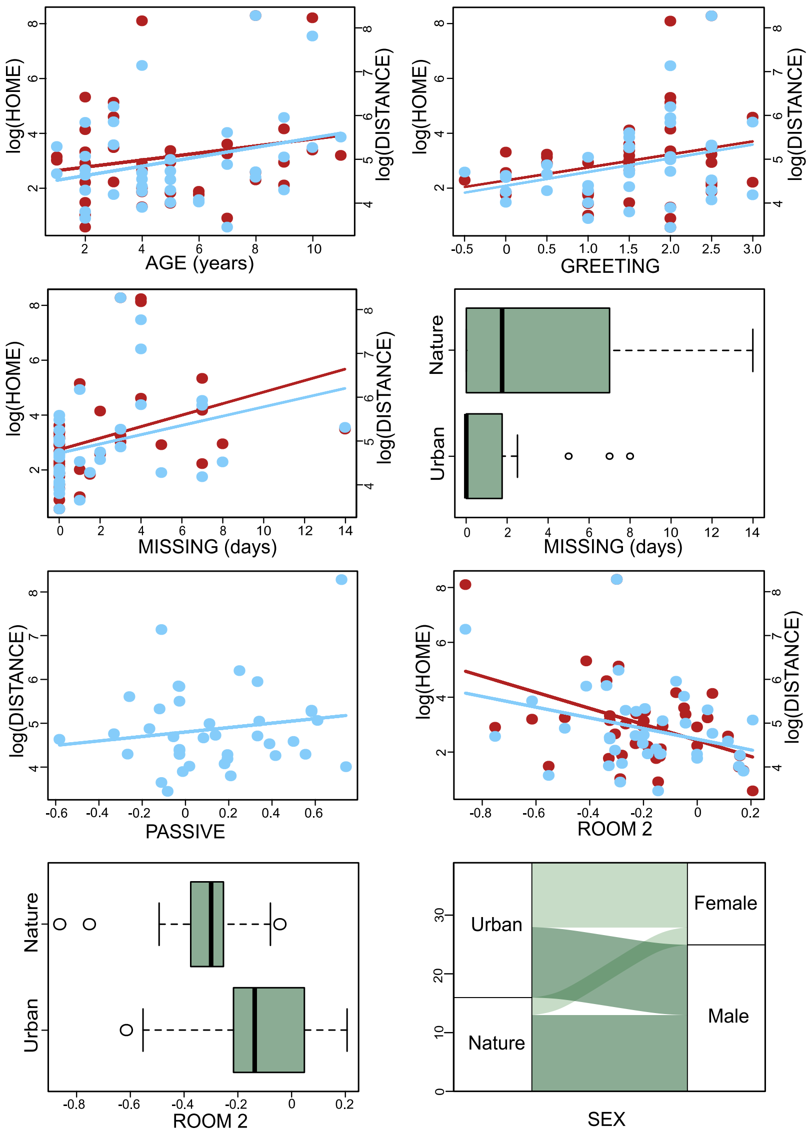

Fig. 4. Predictors from the best model for each model set: BACKGROUND, SSP, and MDORS for free-ranging dog movement in southern Chile, alphabetically ordered. For each response variable different colours are used: logHOME (red), logDISTANCE (blue), and NATURE (green). Solid lines show trends of fitted models. For variable description see Table 1. For PASSIVE, negative values indicate the presence of the stranger, while positive the presence of the caregiver. For ROOM 2, negative values indicate the dog alone, while positive indicate the presence of the stranger.

5. Conclusion

In conclusion, we demonstrate that dog-caregiver bonds significantly influence the roaming behaviour of free-ranging dogs. This opens a new field for mitigating the impacts of dogs on wildlife through culturally adjusted management and education strategies. Dog-positive attitudes and their integration into the family depends on the society and even determines the ability to recognize emotions in dogs (Amici et al., 2019). In general terms, we think that responsible pet ownership policies should be adapted to the socio-cultural context and should not simply be copied from industrialized countries. For Latin America for example, Ceballos et al. (2014) identify a need for increased education on the owner's commitment beyond physical pet care. Actually, the concept of the responsible dog owner itself seemingly is of limited use as a message: The owning behaviour of dog owners in the UK considerably varied in important aspects, although they considered themselves as responsible (Westgarth et al., 2019). This finding is supported by the fact that in our study the dog's perspective on the relationship differed from the caregiver's (all Spearman's correlations between attachment variables and MDORS scales were $P > 0.05$, but see Rehn et al., 2014). In this study, we identify the need for a better understanding of the role of the caregiver as an attachment figure in free-ranging dogs. In specific terms, we recommend using exploration behaviours and the number of days caregivers report their dogs missing to distinguish between dogs that stay close to their homes and dogs with intensive forays. That way, efforts to raise awareness on the dog-wildlife conflict can be focused on caregivers of possible problematic dogs. In form of a simple test and questionnaire, this could be easily addressed through responsible ownership programs. Finally, fostering the knowledge of the importance of bonds between dogs and their owners, such as the lifelong high attachment in dogs (Mongillo et al., 2013), matching of dog-owner endocrine systems (Oliva et al., 2016), and the bond's influence in behaviours relevant for wildlife (this study), will likely help to reduce roaming. The evolution of the dog through domestication can be an ally in conservation: dogs have shown that they prefer to be close to humans. Improving the links between the two species can be beneficial, not only for human and dogs, but also for wildlife.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.applanim.2021.105358.

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