Article

A mathematical approach to study stress-related behaviors in captive golden-bellied capuchins (*Sapajus xanthosthernos*)

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Abstract
Exhibition of stress-related behaviors can be used as a criterion to evaluate the welfare of captive animals. Monitoring animal welfare is important because of ethical and conservation issues. Ethical issues are involved in maintaining animals in an environment similar to nature and conservation issues are related to scientific research and environmental education in zoos. One of the most common captive primates found in Brazilian zoos is the golden-bellied capuchin (*Sapajus xanthosternos*), recognized by its characteristic head coloration with a black or dark brown cap with dark sideburns and golden chest, belly and upper arms. In this paper, we developed a mathematical model that incorporated Fuzzy Theory to study stress-related behaviors in captive golden-bellied capuchin. We defined “number of visitors”, “number of sudden loud sounds inside the zoo” and “feeding period” as input variables and the number of stress-related behaviors observed during a pre-defined time as output variable. We chose Fuzzy Theory because behavioral studies involve imprecision and a fuzzy approach provides the development of algorithms that are able to represent uncertainty inherent in data and can be an advantage in cases where an explicit analytical-process model is not available. We tested the mathematical model by comparing model results to field observations in three zoos from Brazil. This paper has revealed that the fuzzy process is a tool to help studies based on behavioral ecology since the model successfully predicted the number of stress-related behaviors presented by the animals.

Keywords biomathematics; behavioral ecology; fuzzy sets; captive primates.

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1 Introduction

The exhibition of species-typical behavior has been long emerged as a key criterion for evaluating the welfare of captive primates in zoos and research settings (Schapiro et al., 2013). According to Novak (1989), captive animals exhibiting well-being are more similar to their conspecifics in nature. It is desirable that animals display high levels of exploratory and playful behaviors, showing low levels of aggression and stereotyped behavior. Some papers have suggested that alarm vocalizations could be exploited as a useful monitor of subjective well-being (SWB) because of the associations to stereotypical behaviors in aversive social situations (Resende and Oliveira, 2007; Fitchel and Capeller, 2012).It is important to predict and avoid stress-related behaviors since they may indicate zoos that are not achieving their conservation aims.

A possible methodology to predict subjective responses is the use of fuzzy rule-based systems. Fuzzy systems allow the representation of uncertainty inherent in data and the description in linguistic terms of problems where an explicit analytical model is not available or too complicated. Under these conditions, fuzzy techniques allow more accurate conclusions in comparison to the other approaches that cannot be applied successfully because of the lack of data (Zadeh, 1965; Garcia and Peixoto, 2011). The use of this approach to assess animal welfare has already been studied. Pereira et al. (2008) developed a controller based in fuzzy sets to estimate the welfare of broiler breeders in function of frequencies and times of occurrences of behaviors, predicting correctly 80% of the experimental data. Ying et al. (2008) used a fuzzy rule-based system to assess animal welfare management in zoos, testing the model at the Heilongjiang Northeast Tiger Animals Garden and finding good conditions of animal welfare. Borges et al. (2010) created a fuzzy inference system to predict the noise level produced by swine groups under different conditions of temperature and comfort environment conditions.

One of the most common captive primates found in Brazilian zoos is the golden-bellied capuchin (*Sapajus xanthosthernos*) that is recognized by its characteristic head coloration, a black or dark brown cap with dark sideburns and a golden chest and abdomen (Canale et al., 2013; IUCN, 2015). Its distribution is restricted to the Atlantic Forest of southern Bahia, Brazil (Groves, 2005; Flesher, 2015). Because of its limited range of distribution and the continuous deforestation of the Atlantic Forest, this species is classified as "critically endangered" (IUCN, 2015). In zoos, its welfare can be monitored by using the exhibition of stereotypical behaviors as a good indicator of stress in captivity as verified by Resende and Oliveira (2007), who observed that a rumble call vocalization, announcing predator risk, was related to sudden loud noises coming from roads that surrounded the zoo.

In this paper, we developed a mathematical model that incorporated fuzzy theory to predict the number of stress-related behaviors presented by captive golden-bellied capuchins. As model inputs, we defined variables mentioned in the current literature such as number of visitors in the zoo, feeding time and sudden loud sounds. We tested the model by using data on golden-bellied capuchins from 3 zoos located in São Paulo state, Brazil, by comparing field data and the results of the fuzzy model.

After this introduction, the paper proceeds as follows: section 2 presents a brief review of stress-related behaviors in golden-bellied capuchin, the hypotheses that support our model and the description of our fuzzy rule-based systems. In section 3, we verified the predictability of our model for three zoos in Brazil. In section 4, we present a brief discussion about our results. Finally, in section 5, we present the conclusion.

2 Preliminary Concepts and Definition

This section presents the essential components of our model: stress-related behaviors usually presented by golden-bellied capuchins, the background information that supports our model and the structure of the fuzzy rule-based system.

2.1 Stress related-behaviors

We defined three input variables that could influence stress-related behaviors of golden-bellied capuchins in our mathematical model. According to the literature, these variables are the most influent on behaviors of captive primates (Waitt and Buchannan-Smith, 2001; Farrand, 2007; Resende and Oliveira, 2007). They are listed below:

- Sudden loud noises: Resende and Oliveira (2007) observed that sudden explosive noises are one of the causes of alarm vocalization by studying golden-bellied capuchin in the state of São Paulo. They found out alarm vocalization is contingent on thunder, explosions and other explosive noises by conducting an experiment to test the ability to elicit it by producing sudden noises. In this particular case, vocalization was a sort of alarm call impelling monkeys to protect themselves. In zoos, sudden noises are represented by thunders or car engine sound, among others. Some sounds are strange to the animals since they do not occur periodically, being unpredictable and depending on not usual and random events into a zoo.

- Visitors: There is evidence that visitors can affect the behavior of zoo-housed mammals. Farrand (2007) found a positive correlation between density of visitors and number of vigilance behaviors among captive monkeys. According to Mallapur and Chellam (2002), lion-tailed macaques display lower levels of abnormal behavior such as stereotypical pacing while off display to the public. They also perform aggressive behaviors less frequently in the absence of the visitors.

- Food availability: Levels of stress may be associated with fluctuations of food availability in zoos. The influence of daily feeding routines indicates that these events can cause significant behavioral changes in captive primates since they increase aggressive behaviors during pre-feeding periods. According to Waitt and Buchannan-Smith (2001), some captive primates present stereotyped behaviors during periods prior to feeding routines. When animals are waiting to be fed, rates of vocalization and abnormal behaviors increase significantly. The same behavioral pattern is observed when the feeding period is delayed past the mean routine time.

Regarding stress-related behaviors, we selected those that indicate stress in capuchin monkeys based on literature (Honeysett, 2006; Morgan and Tromborg, 2007; Resende and Oliveira, 2007):

- Grimace: Facial expression in which the lips are pulled back and the teeth are bared towards the visitors.
- Vocal behavior: Alarm vocalizations (terrestrial predator alarm).
- Stereotypic pacing behavior: Pacing occurs when the animal moves repeatedly back and forth in a straight line, in a circular or figure eight pattern in its enclosure.
- Vigilance behavior: The animal keeps in visual and acoustic attention.

Thus, a sum of all stress-related behaviors, *S,* observed during a time interval, *t*, was defined as output of our system.

2.2 Model background information

In this section, we present the background information that we used to create the rules of our fuzzy model.

Regarding the feeding time in captive conditions, stress-related behaviors increase during pre-feeding periods for adult monkeys (Waitt and Buchanan-Smith, 2001) and only female stress-related behaviors decrease after feeding. Males remain stressed during and after feeding because the capuchin group may become vulnerable to predation and he is the most active in protecting the group from predators and other groups of monkeys (Zoological Wildlife Foundation, 2008).

Female golden-bellied capuchin is affected by the feeding period and number of visitors (Waitt and Buchanan-Smith, 2001; Farrand, 2007). She is more sensitive than the male in relation to the pre-feeding time because it is her role to provide food to the young capuchins. Female primates have evolved to maximize the offspring survival by nurturing baby monkeys (Taylor et al., 2000).

Meanwhile the female golden-bellied capuchin is affected only by the feeding period and the number of visitors, the male is also affected by sudden loud noises because of his role of leader and protector of the group (Boinski et al., 1999; Zoological Wildlife Foundation, 2008). This also implies in a higher sensitivity to visitors since the dominant male reacts to any threat of invasion in his territory, leading attacks to drive invaders away (Zoological Wildlife Foundation, 2008). Therefore, the male golden-bellied capuchin presents a high number of stress-related behaviors when the number of visitors and the frequency of sudden loud sounds are high.

2.3 Fuzzy rule-based system (FRBS)

Fuzzy Theory was first defined by LoftiZadeh to represent uncertain and imprecise knowledge (Zadeh, 1965; Ferrarini, 2011). Fuzzy rule-based systems have four components: an input processor (fuzzification), a collection of linguistic rules called rule base, a fuzzy inference method and an output processor (defuzzification) (Sivanandam et al., 2007; Garcia and Peixoto, 2011).

In the current work, we developed a mathematical model that incorporated FRBS to predict the number of stress-related behaviors in golden-bellied capuchins constituted by two fuzzy systems: one for males and another for females. The model was programmed by using the Fuzzy Logic Toolbox^{TM}.

Regarding males, input variables were previously defined in section 2.1: “number of visitors”, “number of sudden loud sounds inside the zoo” and “feeding period” and the output variable was the sum of all stress-related behaviors observed during a pre-defined period of 10 minutes of observation. Regarding females, input variables were the same of the males, except “number of sudden loud sounds inside the zoo”, which affects only males.

Fuzzification is the process in which the input values of the system are translated into fuzzy sets of their respective universes. It is a mapping of the real numbers domain leading to the fuzzy domain. This process is based on the knowledge of a specialist, who is someone that has been working on the study case, playing an important role to build membership functions for each fuzzy set associated to the inputs (Zadeh, 1965; Ross, 2000). Specialists define qualitative variables associated to each set and the range covered by each one. In our study, fuzzy sets (Fig. 1-5) were defined by using unpublished field notes (Garcia AG. 2012. Unpublished field notes recorded at the *Quinzinho de Barros* Zoo) recorded at the *Municipal Zoological Park Quinzinho de Barros* in Sorocaba, state of São Paulo, Brazil. In this unpublished work, field data were collected by observing the social behavior of two golden-bellied capuchins (one adult male and one adult female) over 120 observation hours, 4 hours a day during November, 2012. The study group was located on an island. It was used focal animal sampling, in which all occurrences of specified actions of one individual were recorded during a pre-determined sample period of 10 minutes, therefore the model output was a discrete variable. It was estimated the number of visitors in a radius of 30 feet from the island and the number of sudden loud noises during this time interval. Feeding time occurred between 3:00 to 4:00 pm. The results showed a correlation coefficient equal to 0.35 ($P < 0.05$) between number of visitors and number of stress-related behaviors and equal to 0.63 ($P < 0.05$) between number of sudden noises and number of stress-related behaviors for the male. For the female, the correlation coefficient was smaller than 0.1 ($P < 0.05$) in both cases. Additionally, the average number of stress-related behaviors one hour before feeding was equal to 1.11 stress-related behaviors per sample period and one hour after feeding was equal to 2.55 for the male. Regarding female, the average number one hour before feeding was equal to 3.47 and one hour after feeding was equal to 0.24.

These field notes confirm the background information from literature (subsection 2.2). Males are more affected by the number of visitors and the number of sudden noises than females because they are protecting the group. On the other hand, the female is more affected by the pre-feeding period than the male, therefore her stress decreases after feeding. The opposite happens to the male, i.e., his stress increases after the feeding time to protect the group, because monkeys get vulnerable when they are feeding.

Based on these field notes, it was also possible to classify the number of visitors in three categories according to the period of the day: “Low” (0 - 15 people) from 9:00 am to 10:00 am (when zoo opens), from 12:00 am to 1:00 pm (lunchtime) and from 4:00 pm to 5:00 pm (when zoo closes); “Medium” (10 - 25 people)from 10:00 am to 1:00 pm and from 2:00 pm to 4:00 pm, except on weekends and holidays; “High” (18 - 35 people)from 10:00 am to 1:00 pm and from 2:00 pm to 4:00 pm on weekends and holidays. The period of the day was also classified in: “Pre-feeding”, which represents the period before feeding time, when animal is quiet; “Pre-Feeding 2”, which represents the period before feeding time, when animal gets nervous waiting for food (only females); “Feeding”, which is the proper feeding time and “After feeding” (only males). Regarding the sounds, we considered car engines and thunders among others as sudden loud sounds inside the zoo (Resende and Oliveira, 2007) when they were above 80 dB (decibels). Fuzzy sets were defined as follows:

- Fuzzy sets of the input variables “number of visitors” were *low, medium* or *high*;
- Fuzzy sets of the input variable “feeding period” were *pre-feeding*, *feeding* or *after feeding* (males) *and pre-feeding1*, *pre-feeding2 or feeding* (females);
- Fuzzy sets of the input variable “number of sudden loud noises” were *low, medium* or *high;*
- Fuzzy sets of the output variable “sum of all stress-related behaviors (*S*)” were *low, medium* or *high*.

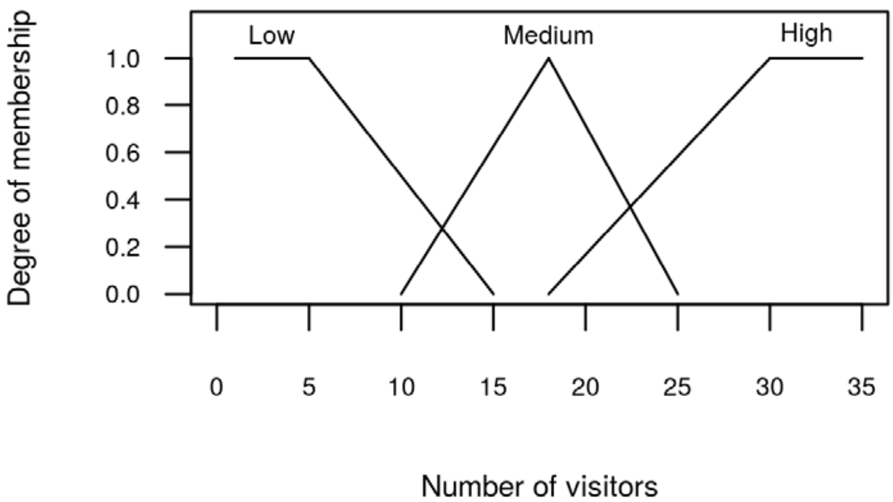

Fig. 1 Fuzzy sets for “Number of visitors”.

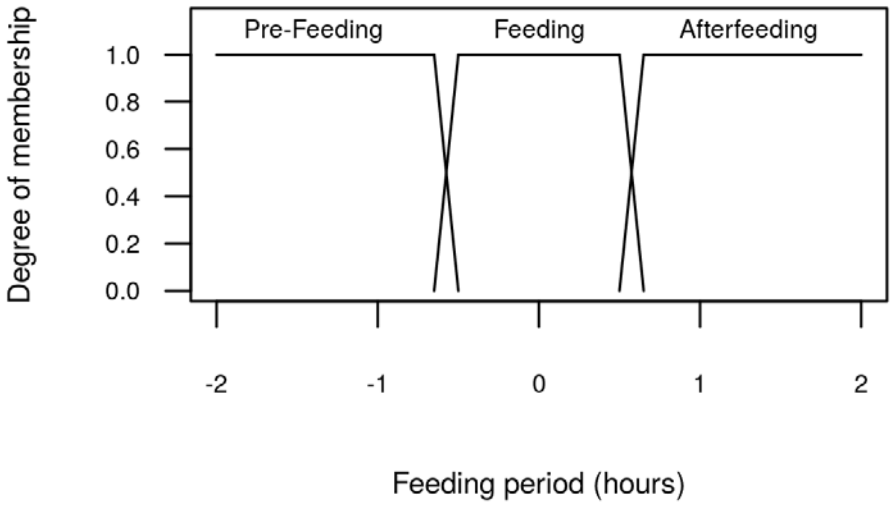

Fig. 2 Fuzzy sets for "Feeding period" (male). "0" corresponds to the exact time when the monkeys receive food.

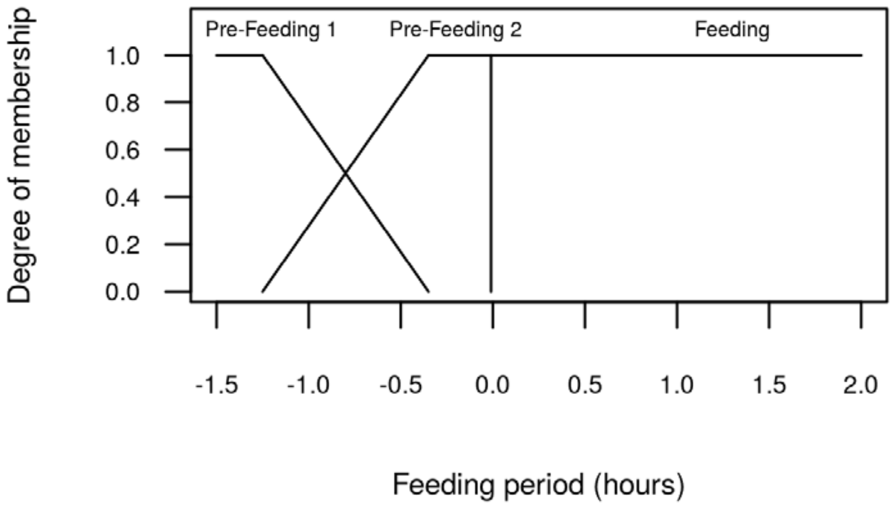

Fig. 3 Fuzzy sets for "Feeding period" (female). "0" corresponds to the exact time when the monkeys receive food.

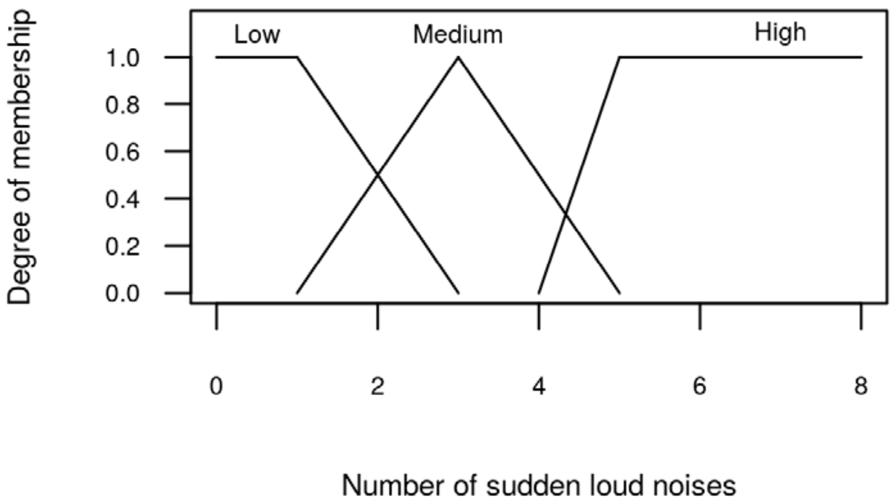

Fig. 4 Fuzzy sets for "Number of sudden loud noises".

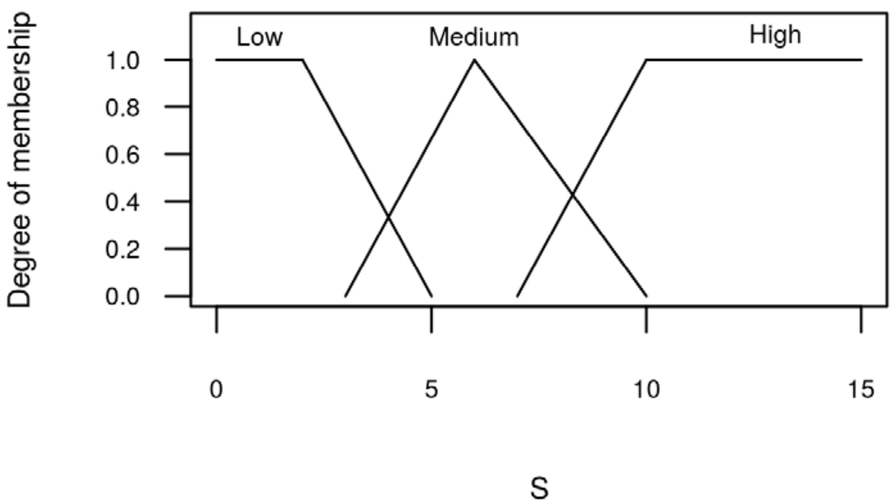

Fig. 5 Fuzzy sets for *S* (output).

The rule base characterizes the objectives and strategies used by specialists in the study by using a linguistic rule set. It is composed by a collection of fuzzy conditional propositions in the form if-then rules (Adriaensses et al., 2004).

We formulated the fuzzy rule base supported by the available literature (see section 2.2) and the unpublished notes at the zoo. The fuzzy rule base was given by 27 rules for males and 9 for females because this number corresponds to all possible combinations between the variables. We listed some of them below:

- Male

- IF the number of visitors is "High" AND the period is "Pre-feeding" AND the number of sudden loud sounds is "Low", THEN *S* is "Medium".

- IF the number of visitors is “Medium” AND the period is “Feeding” AND the number of sudden loud sounds is “High”, THEN *S* is “High”.

➢ Female

- IF the number of visitors is “Low” AND the period is “Pre-feeding 2”, THEN *S* is “Medium”.
- IF the number of visitors is “Medium” AND the period is “After feeding”, THEN *S* is “Low”.

The fuzzy inference method performs an approximate reasoning using the compositional rule of inference. A particular form of fuzzy inference is the Mamdani method (Mamdani, 1977). It aggregates the rules through the logical operator OR, modeled by the maximum operator and, in each rule, the logical operators AND and THEN are modeled by the minimum operator (Klir and Yuan, 1995).

Finally, in defuzzification, the value of the inferred output linguistic variable from the fuzzy rule is translated to a real value. A typical defuzzification scheme, the one adopted in this paper, was the centroid or center of mass method. We suggest Pedrycs and Gomide (2012) and Klir and Yuan (1995) for a detailed study of fuzzy sets theory and applications.

3 Simulation Results

In order to verify the predictability of our model, we collected data from 3 zoos in São Paulo state, Brazil, during November, 2013. Field data were collected by observing the social behavior of two golden-bellied capuchins (one adult male and one adult female) over 5 hours using focal animal sampling method with sample periods of 10 minutes in intervals of 2 minutes. During this period, we recorded the number of visitors into a radius of approximately 30 feet as well as the number of sudden loud sounds. These data were used as model input to verify if the model output corresponded to the number of stress-related behaviors observed in field.

➢ Zoo 1: In the first visited zoo, the monkeys were located on an island, measuring approximately 30 feet on each side. The group was composed by 2 adult monkeys (one male and one females). The maximum distance for which the visitors could get close to the monkeys was approximately 30 feet. Predicted (model results) and observed *S* values (field data) were not significantly different at the 5% level by using the Fisher's Exact Test for the male (N = time intervals =25, p = 0.99) and for the female (N = 25, p = 0.855) (Table1).

➢ Zoo 2: In the second visited zoo, the monkeys were located on an island, measuring approximately 30 feet on each side. The group was composed by 3 adult monkeys, however only one male and one female were studied. The maximum distance for which visitors could get close to the monkeys was approximately 60 feet. Predicted (model results) and observed *S* values (field data) were not significantly different at the 5% level by using the Fisher's Exact Test for the male (N = 25, p = 0.81) and for the female (N = 25, p = 0.99) (Table 2).

➢ Zoo 3: In the third visited zoo, the monkeys were located on an island, measuring approximately 30 feet on each side. The group was composed by 8 adult monkeys, however only one male and one female were studied. The maximum distance for which visitors could get close to the monkeys was approximately 30 feet. Predicted (model results) and observed *S* values (field data) were not significantly different at the 5% level by using the Fisher's Exact Test for the male (N = 25, p = 0.72) and for the female (N = 25, p = 0.32) (Table 3).

Table 1 Variables observed in field and the correspondent *S* values provided by the model in the two first hours of observation. V- visitors; SN – sudden noises; FP- feeding period in hours (“0” corresponds to the exact time when monkeys receive food, negative values correspond to pre-feeding periods and positive values correspond to the after feeding period); OS- observed *S*; PS- predicted *S*; M – male; F – female.

V	SN	FP	OS(M)	PS(M)	OS(F)	PS(F)
5	0	-1.2	2	2	2	1
6	2	-1	4	5	3	3
12	0	-0.8	2	2	5	4
2	0	-0.6	1	2	0	4
9	0	-0.4	0	2	3	6
7	0	-0.2	2	2	6	9
6	0	0	2	2	4	1
9	0	0.2	2	2	1	1
11	0	0.4	3	3	0	1
14	0	0.6	5	6	0	1

Table 2 Variables observed in field and the correspondent *S* values provided by the model in the two first hours of observation. V- visitors; SN – sudden noises; FP- feeding period in hours (“0” corresponds to the exact time when monkeys receive food, negative values correspond to pre-feeding periods and positive values correspond to the after feeding period); OS- observed *S*; PS- predicted *S*; M – male; F – female.

V	SN	FP	OS(M)	PS(M)	OS(F)	PS(F)
11	0	-4	0	2	0	0
13	0	-3.8	0	2	0	0
7	0	-3.6	1	2	0	0
15	0	-3.4	1	2	0	0
16	0	-3.2	2	2	1	0
8	0	-3.0	3	2	0	0
8	0	-2.8	2	2	0	0
12	0	-2.6	0	2	0	0
11	0	-2.4	4	2	0	0
14	1	-2.2	4	4	1	0

Table 3 Variables observed in field and the correspondent *S* values provided by the model in the two first hours of observation. V- visitors; SN – sudden noises; FP- feeding period in hours (“0” corresponds to the exact time when monkeys receive food, negative values correspond to pre-feeding periods and positive values correspond to the after feeding period); OS- observed *S*; PS- predicted *S*; M – male; F – female.

V	SN	FT	OS(M)	PM(M)	OS(F)	PS(F)
4	0	-0.5	2	2	1	3
3	2	-0.3	7	5	3	3
4	0	-0.1	7	6	2	3
4	0	0.2	0	2	0	0
5	1	0.4	1	2	0	0
2	0	0.6	0	2	0	0
5	0	0.8	0	2	0	0
4	1	1	1	2	0	0
3	0	1.2	1	2	0	0
6	0	1.4	0	2	1	0

4 Discussion

In general, the model successfully predicted the number of stress-related behaviors observed in field. It may represent an improvement in predicting stress-related behaviors of captive animals, supporting biologists and zookeeper decisions to change captivity environment in order to decrease the stress and increase animal welfare. For instance, by using model predictions, it is possible to determine a maximum number of visitors in order not to stress the animals or develop strategies in order to reduce the number of loud sounds close to the cages.

However, the model presented some limitations. In zoo 3, the difference between the observed and the expected *S* was higher (smaller p-value). A possible explanation can be associated to the higher number of monkeys inside the group resulting in a more complex social net between the individuals and implying in different patterns of behavior than a study case with two or three monkeys. Since the model only considers external factors influencing the animals, when the monkeys interact among themselves, the response becomes more unpredictable.

The model also worked better when the number of stress-related behaviors (*S*) did not surpass 6 per time interval. We observed that above this value, golden-bellied capuchins are so stressed that their behavior becomes more unpredictable.

5 Conclusion

Fuzzy Theory is an alternative to model stress-related behaviors in captive golden-bellied capuchins when the group is small, since we were able to predict significantly golden-bellied capuchin behaviors by using the mathematical model. Such mathematical approach fits to our study case because we are working with subjective data. Fuzzy Theory has shown us some advantages in modelling as overcoming the difficulty in representing the unpredictability in ethological data and describing qualitative data by using linguistic rules rather than parameters. This approach is more similar to the data set in behavioral studies.

The model may support biologists and zookeepers decisions in order to change captivity environment, increasing animal welfare. A future approach may be the development of similar fuzzy systems for other animals inside a zoo. Therefore, a data set could be created to store information related to all captive animals living inside a zoo.

Additionally, the model can provide useful results to be used in robotic because it also represents an artificial intelligence (AI) system that simulates inherent behaviors to an animal. Such system can be used to create robots or other AI system that aim to be similar or emulate animals.

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