



# Network social dynamics of an ex-situ colony of African penguins following the introduction of unknown conspecifics

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## ABSTRACT

Zoos often alter social groups by moving individuals between collections to control numbers, maintain optimal genetic diversity, and for husbandry and management purposes. However, the impact of introducing new individuals into an existing social group is overlooked, and the consequences of these stressful events from an animal welfare perspective are underestimated. In this study, we use Social Network Analysis (SNA) to monitor and to investigate how the social dynamics of a colony of African penguins (*Spheniscus demersus*,  $n = 19$ ) were affected by the introduction of groups of unfamiliar individuals ( $n = 6$  and then  $n = 10$ ) at different time intervals. The proximity data collected over a period of four months suggest that penguins established a non-random association and developed a significant level of preferred associations within the colony. Breeding pairs had a high degree of interaction with the rest of the colony, and their level of association was stable even when a new group was introduced. We found that the association preferences observed in the colony after introduction were not driven by sex and reproductive age. Instead, the main driver of association was the time of introduction, with individuals introduced at the same time being more likely to interact than those introduced at different times. We also speculate that, in addition to arrival time, familiarity plays a key role in group integration. In our specific case, the introduced penguins were already familiar with each other, having shared the same colony before arriving at the new one. Although the results are based on a case study and require further validation, they support the importance of maintaining relevant social ties within colonies and of relocating a few selected individuals who share prior familiarity to facilitate integration into a new colony. Our findings highlight the usefulness of implementing SNA to evaluate the impact of stressful events on the lives of animals.

## 1. Introduction

Understanding the social dynamics of group living species can shed light on the evolution of complex societies and can play a pivotal role in guiding applied conservation efforts, refining husbandry regimes, and implementing welfare actions (Abell et al., 2013; Brown et al., 2019; Caro, 1999; Wey et al., 2008). Notably, a deep understanding of social dynamics can provide input vital for empowering zoo management to make informed decisions from an animal-based welfare perspective (Lewton and Rose, 2021). Social Network Analysis (SNA) provides a quantitative measure to describe complex relationships among

individuals and can characterise the role of individuals within a network (Borgatti et al., 2009; Farine and Whitehead, 2015). Unsurprisingly, in recent years SNA has become one of the key tools for evaluating whether zoo management actions preserve the advantages of sociality in species housed in captive settings (Rose and Croft, 2015).

For example, SNA studies of various species of flamingo (Order Phoenicopteriformes) housed under human care have highlighted how these birds have a long-lasting specific preferential association within a flock, and how age, sex, and personality can drive the formation of specific bonds within a flock (McCully and Rose, 2023; Rose and Croft, 2017). Similarly, in another study on a captive herd of Rothschild's

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giraffes (*Giraffa camelopardalis rothschildi*), SNA provided strong evidence for the formation of specific bonds between females and females-offspring, non-random associations among the herd, and flexibility in selecting preferred social partners (Lewton and Rose, 2020). The investigation of social dynamics of Asian elephants (*Elephas maximus*) and African elephants (*Loxodonta africana*) showed that positive interactions tended to include the entire herd compared to negative interactions, which appeared to be restricted to specific individuals (Williams et al., 2020). The application of SNA has also made it possible to evaluate the social response to a change in environmental conditions in a group of chimpanzees (*Pan troglodytes*) experiencing space reduction. Indeed, unidirectional grooming network was found to be lower and less cohesive when chimpanzees experienced space reduction (Koyama and Aureli, 2019). Overall, the applications of SNA in *ex-situ* social groups provide valuable recommendations for the effective management and maintenance of social stability among animals in human care, contributing to the improvement of their welfare conditions (Rose and Croft, 2015).

Although the SNA has been extensively used in *ex-situ* for different purposes (Lewton and Rose, 2021), in the last few decades the impact of adding individuals into an established group has been overlooked and studied in only a few cases, compared to instances when individuals are removed. For example, Ryan and Hauber (2016) examined the compositional changes of a group of captive hamadryas baboons following the introduction of two females. During the time of introduction, hamadryas baboons increased affiliative behaviour, most likely to reduce the tension of a social stress event. Similarly, Radosevich and co-authors (2021) used SNA to investigate the social dynamics of a captive hamadryas group following the introduction of two young males (see also Molinaro et al., 2022). The introduction of the two young males decreased the overall group cohesion, and the impact was most prominent on resident males compared to females. In addition, SNA provided valuable information on integrating the two males in the host group, suggesting the formation of a one-male unit forerunner of harem social structure. Although SNA is an important tool for monitoring the dynamics of social life following an introduction into an existing group, it has only been applied to a limited number of zoo-housed groups and these are mainly restricted to primates (Beisner et al., 2015, 2011; Flack et al., 2006, 2005; Hansen et al., 2009; Less et al., 2010; McCowan et al., 2011; Ryan and Hauber, 2016; Schel et al., 2013).

The goal of this study is to investigate the social changes caused by introducing new individuals to an existing social group of African penguins (*Spheniscus demersus*). Often, zoological facilities control group size and composition by moving and introducing individuals to different colonies to maintain optimal genetic diversity by limiting inbreeding within colonies (Bos et al., 2016; EAZA, 2013). Currently, 2219 African penguins are housed in 65 *ex-situ* facilities, and 503 individuals were translocated between structures between 2019 and 2023 (data collected from the Zoological Information Management System). Although group composition is altered by the movement of individuals between zoos, it is remarkably unknown whether the introduction of individuals alters the social structure of an existing colony of African penguins. Similarly, there is no indication of how the effects of group manipulation (if any) might be reduced. African penguins are monogamous and consequently form long-term bonds with their partners (Baciadonna et al., 2021) that are qualitatively different from those they form with their colony mates (Borboroglu and Boersma, 2013; Eggleton and Siegfried, 1979). In this study, we aim to describe the social network structure of an *ex-situ* African penguin's colony when groups of new individuals were introduced at two different time intervals. We predicted a prevalence of intragroup interactions over intergroup interactions among penguins, suggesting that these birds tend to closely associate within their original groups, leaving the host colony's social structure stable. Based on their breeding strategy, we predicted that established breeding pairs would maintain higher dyad interactions following the group introduction. We also expected that unpaired individuals would be positively associated with

individuals of the opposite sex.

## 2. Methods

### 2.1. Ethics statement

Our study complied with all regulations for animal care in Italy. According to Italian law, no specific permission was needed because colony activities were recorded from outside their exhibit. All procedures were also conducted in accordance with the guidelines of the Association for the Study of Animal Behaviour (2023) for the care and use of animals for research activities.

### 2.2. Subjects

This study was conducted at Zoom Torino (Italy) from 16/09/2021–16/12/2021, for a total of 23 days of observations. At the beginning of the study, the colony consisted of 25 adult penguins (13 females and 12 males; see also Table 1 for extra detailed information on each penguin), which included six female individuals (moved from Parc Zoologique Safari de Peaugres, France) introduced at the beginning of the colony observation (16/09/2021). On 13/10/2021 a new group of ten penguins (two females and eight males; all from Zoo Wrocław, Wrocław, PL) was subsequently introduced to the host colony (15 females and 20 males). Four penguins died during data collection.

### 2.3. Behavioural data collection

The behavioural data were collected from the colony housed at Zoom Torino over a 23-day period, totalling 47.5 hours of observations. Between 16/09/2021 and 12/10/21, nine days of observations were conducted with a range of 2–5 scan sampling each day. Subsequently, from 13/10/2021–16/12/2021, 14 days of observation were conducted with a range of 2–8 sampling each day. Instantaneous sampling occurred every 30 minutes for the entire group, with penguins within one body width of each other recorded as associating (Proximity). One to four hours of data collection were conducted each day to allow for a wide range of the penguins' activities. Due to the daily husbandry regimes, number of visitors and weather conditions, the earliest scan was recorded at 9 am and the latest at 1:30 pm.

### 2.4. Statistical analysis

We constructed two networks using the *igraph* (Gábor and Tamás, 2006) package in R (R Development Core Team, 2021, v 4.1.0). The first network (i.e. Network 1) encompassed observations from the start date of 16/09/2021 until 12/10/2021. Network 1 included 19 penguins, along with the six females relocated from Parc Zoologique Safari de Peaugres. The second network (i.e. Network 2) covered observations from 13/10/2021, the day the second set of penguins (10 subjects) was introduced to the host colony, to 16/12/2021. For each network, we calculated the proportion of time pairs of individuals were observed in proximity using the Simple Ratio Index (*asnipe* package in R; Farine, 2013).  $SRI = x/x + y_{AB} + y_A + y_B$ , where  $x$  = number of events individuals A and B were observed in proximity;  $y_A$  and  $y_B$  = number of events in which A or B, respectively, were observed alone;  $y_{AB}$  = number of events in which neither A nor B were observed. Subsequently, to identify clusters of associations between individuals, we used a *cluster-fast greedy algorithm* (Clauset et al., 2004) implemented in the *igraph* package in R. Specifically, clusters occur when intra-group interactions are greater than inter-class interactions. When clusters are detected, it suggests that individuals in the same cluster are more likely to be seen in proximity. To evaluate the relationship between time of introduction, sex (dichotomous variable: "male" and "female"), reproductive stage (coded as dichotomous variable: "no" = <3.5; "yes" >3.5) and the observed associations between individuals, we applied a Multiple Regression

**Table 1**

**Individuals' composition at Zoom colony at the time of the study.** I.D. = Code used during the observations for each individual, Name = Penguins code as registered by The European Association of Zoos and Aquaria (EAZA), Colony of Provenience indicates the colony from which they come before being introduced at the Zoom, Sex indicates the sex of the identity of the penguins (I.D.), Date of hatching and finally Date of Arrival indicates the date when the penguins were introduced to Zoom Torino colony. The asterisks identify penguins that passed away during the data collection.

I. D.	Name	Colony of Provenience	Sex	Date of Hatching	Date of Arrival
A	ALFA	South Lake Wild Animal Park, UK	F	14/12/1987	01/07/2009
B	RICO	South Lake Wild Animal Park, UK	M	26/10/2006	01/07/2009
C	AMADI	South Lake Wild Animal Park, UK	F	13/11/2005	01/04/2009
D	RED	Zoom Torino, Italy	M	20/10/2010	20/10/2010
E	KYR	Zoom Torino, Italy	F	12/03/2013	12/03/2013
F	GIGI	Zoom Torino, Italy	M	01/03/2014	01/03/2014
G	VIOLET	Zoom Torino, Italy	M	06/09/2010	06/09/2010
H	RAS	Zoom Torino, Italy	F	18/04/2012	18/04/2012
I	SKY	South Lake Wild Animal Park, UK	M	28/10/2004	01/04/2009
J	HARLOCK*	South Lake Wild Animal Park, UK	M	24/10/2003	01/07/2009
K	JOKER	South Lake Wild Animal Park, UK	M	28/09/1991	01/07/2009
L	RASHIDA*	South Lake Wild Animal Park, UK	F	14/12/1991	01/07/2009
M	DRED*	Zoom Torino, Italy	M	25/10/2018	25/10/2018
N	ELLIOT	Zoom Torino, Italy	M	12/03/2019	12/03/2019
O	EGLE	Zoom Torino, Italy	F	11/03/2019	11/03/2019
P	E.D.*	Zoom Torino, Italy	M	10/11/2019	10/11/2019
Q	FUNNY	Zoom Torino, Italy	M	18/09/2020	18/09/2020
R	FEBE	Zoom Torino, Italy	F	01/03/2020	01/03/2020
S	FRED	Zoom Torino, Italy	M	08/03/2020	08/03/2020
T	HAM (ROUGE)	Le safari de Peaugres, France	F	04/10/2006	16/09/2021
U	CHAMPAGNE	Le safari de Peaugres, France	F	09/10/2013	16/09/2021
V	CHOCOLATE	Le safari de Peaugres, France	F	09/02/1999	16/09/2021
W	BRIE	Le safari de Peaugres, France	F	28/12/2015	16/09/2021
X	BAGUETTE	Le safari de Peaugres, France	F	31/12/2015	16/09/2021
Y	CHARLOTTE	Le safari de Peaugres, France	F	15/10/2011	16/09/2021
Z	ZIELONY	Zoo Wroclaw, Poland	M	16/10/2020	13/10/2021
AA	PEPE	Zoo Wroclaw, Poland	M	06/11/2020	13/10/2021
BB	HOUDINI	Zoo Wroclaw, Poland	M	08/06/2019	13/10/2021
CC	ACHAD	Zoo Wroclaw, Poland	F	18/05/2017	13/10/2021
DD	BUTTHEAD	Zoo Wroclaw, Poland	M	14/02/2016	13/10/2021
EE	NICKI MINAJ	Zoo Wroclaw, Poland	F	04/05/2016	13/10/2021
FF	HYZIO	Zoo Wroclaw, Poland	M	13/03/2015	13/10/2021
GG	KILLER MIKE	Zoo Wroclaw, Poland	M	06/05/2020	13/10/2021

**Table 1 (continued)**

I. D.	Name	Colony of Provenience	Sex	Date of Hatching	Date of Arrival
HH	SKEKSIS	Zoo Wroclaw, Poland	M	11/05/2020	13/10/2021
II	MAMMA MIA	Zoo Wroclaw, Poland	M	27/03/2019	13/10/2021

Quadratic Assignment Procedures (MRQAP), implemented in the *asnipe* package (Dekker et al., 2007; Farine, 2013; Lewton and Rose, 2020). In MRQAP testing, one association matrix is treated as the dependent factor, and the remaining matrices are considered predictors. The analysis assesses whether the similarity within each predictor significantly contributes to explaining the dependent matrix while accounting for the influence of other predictors. Significant positive correlations suggest that social preferences are possibly driven by assortative effects (e.g., individuals introduced together tend to interact more between them than with individuals introduced in a different moment). In contrast, negative correlations suggest social preferences based on opposite categories (e.g., males interact more with females than with males).

Furthermore, for each network, we tested the null hypothesis of random associations versus the alternative that pairs of individuals exhibit preferred or non-preferred associations (Bejder et al., 1998). This was done using the *network\_permutation* function implemented in the *asnipe* package (Farine, 2017, 2013; Farine and Carter, 2022). Initially, we calculated the observed Coefficient of Variation (CV) of the real association network (SRI) and then compared it with the CV expected by chance. We repeated this process until the CV P value stabilised over 1000 permutations, which were generated by using the *pre-network\_permutation* function in the *asnipe* package (Farine and Carter, 2022). Statistical differences between the observed CV of each network and the one expected by chance were assessed using a Wilcoxon signed-rank test. Secondly, if the null hypothesis of random associations was rejected, indicating a non-random association, we compared the observed SRI of each dyad with the SRI distribution obtained from 1000 permutations. For each permutation, all possible dyads were categorized as associated if the observed SRI value exceeded the 95% confidence interval of the distribution expected by chance (a similar approach was used in Goumon et al., 2020). Subsequently, a percentage of dyadic association was calculated for all dyads.

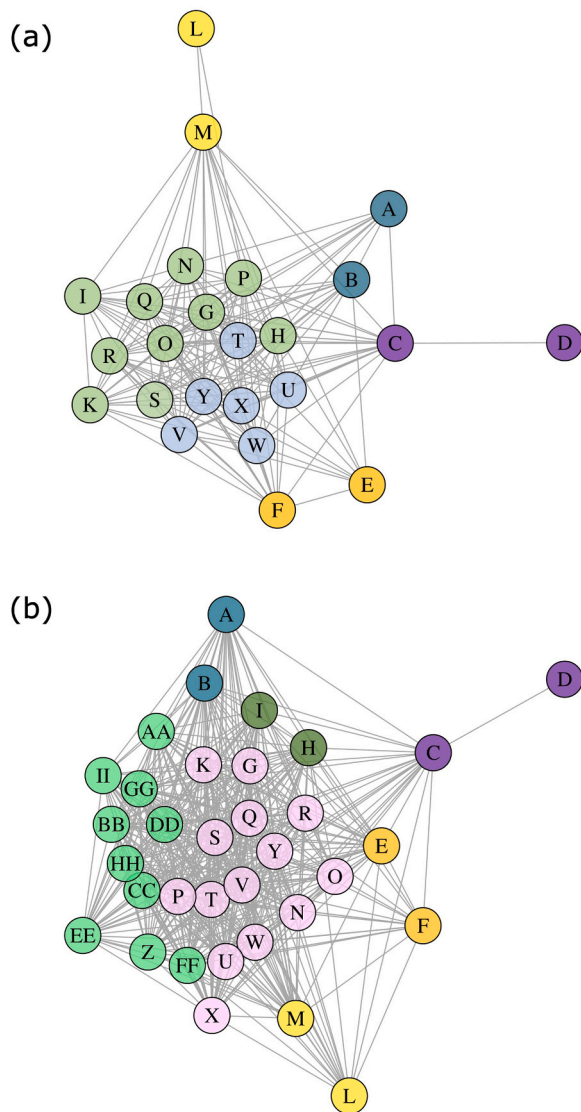
## 2.5. Results

Cluster analysis conducted for Network 1 revealed six clusters (Fig. 1a). Among these, four clusters corresponded to breeding partners residing at the host colony (Fig. 1a and Table 1; dyads: A-B, C-D, E-F, and L-M). Another cluster encompassed the remaining individuals of the host colony, excluding the breeding partners. Finally, the last cluster included the six females introduced in the host colony.

The MRQAP model (adjusted  $R_2 = -0.0004$ ) suggested that neither sex (estimate = 0.010,  $p = 0.43$ ), nor time of arrival at the host colony (estimate = 0.014,  $p = 0.35$ ), or reproductive stage (estimate =  $-0.003$ ,  $p = 0.85$ ) correlated with the association matrices observed in Network 1.

The significantly large observed CV of the association index (CV = 135.17, Wilcoxon signed-rank  $V = 26425$ ,  $p = 2.2 \times 10^{-16}$ ) indicates the existence of social preferences. We identified 112 non-random dyads in which the observed SRI value exceeded the 95% confidence interval of a random distribution (Fig. 2a). Four dyads spent more than 40% of their time exclusively interacting with their dyad partner (range 42% – 84%) and, based on the historical database, these were identified as breeding partners.

Cluster analysis conducted for Network 2 revealed five clusters (Fig. 1b). Two clusters corresponded to two breeding partners (Fig. 1b);



**Fig. 1. Networks representation of the two-time intervals.** a) Network 1 (from 16/09/2021–12/10/2021) from 24 individuals which includes the first 6 penguins introduced in the host colony. The *cluster-fast greedy algorithm*. The first four represent the breeding partners (dyads: A-B, C-D, E-F, and L-M). The fifth cluster instead represents the rest of the individuals of the host colony excluding the breeding partners (green light colour) and finally the last cluster includes the first six females introduced in the host colony (blue light colour). b) Network 2 (from 13/10/2021–16/12/2021) from 34 individuals which includes the 10 individuals introduced to the colony. The *cluster-fast greedy algorithm*. The first two clusters represent two breeding partners living at the host colony (dyads: A-B and L-M). The third cluster includes three breeding partners (dyads: C-D, E-F, and H-I). The fourth cluster represents the individuals of the host colony excluding the breeding partners merged with the first group of females introduced (bright green) and the fifth cluster are the last 10 penguins introduced in the host colony (light pink). Nodes of the network represent individuals and links the SRI (Simple Ratio Index).

dyads: A-B and L-M). Another cluster comprised three breeding partners (Fig. 1b; and Table 1; dyads: C-D, E-F, and H-I). Finally, two clusters were represented by: 1) individuals of the host colony including the six females introduced on 16/09/2021 and 2) the group of ten penguins introduced on 13/10/2021.

The MRQAP model (adjusted  $R_2 = 0.05$ ) suggested that the time of arrival at the host colony (estimate = 0.032,  $p < 0.0001$ ), but not sex (estimate = 0.005,  $p = 0.35$ ), or reproductive stage (estimate = 0.00002,  $p = 0.997$ ) correlated with the association matrices observed in Network

2.

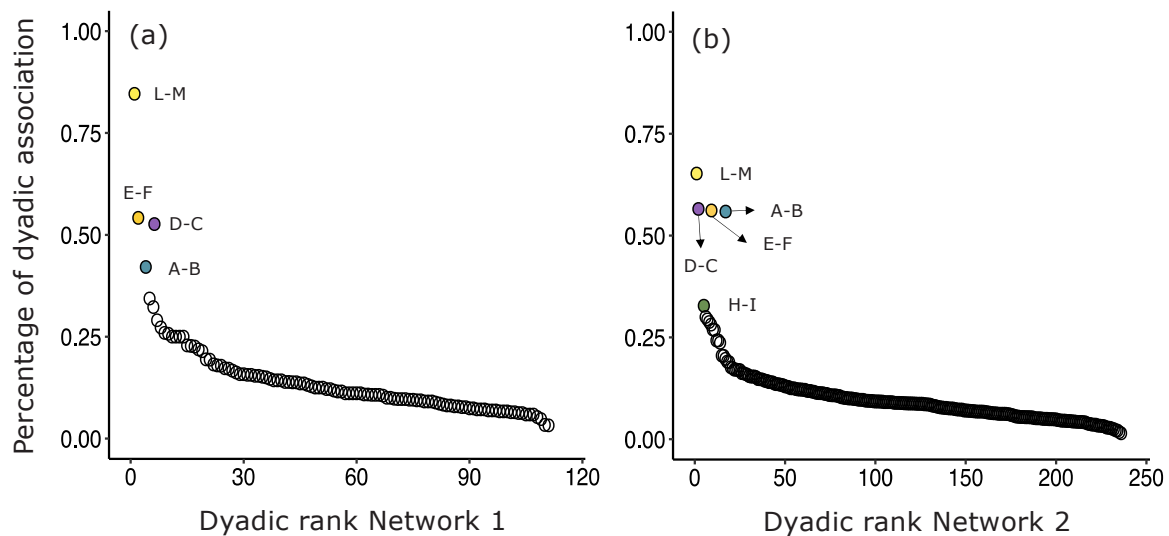
The significantly large observed CV of the association index (CV = 121.14, Wilcoxon signed-rank  $V = 20095$ ,  $p = 2.2 \times 10^{-16}$ ) indicated the existence of social preferences. We identified 219 non-random dyads in which the observed SRI exceeded the 95% confidence interval of a random distribution (Fig. 2b). We identified the same four dyads observed in Network 1 (range 55% – 65% of dyad association), and we also identified a new emerging dyad (H-I, 32% of dyad association).

### 3. Discussion

Our results showed that African penguins form a highly interlinked network with non-random associations. In addition, we found a significant level of preferred associations within the network. As expected, the breeding pairs had a high level of interactions with their partners compared to their overall relationships with the rest of the colony members, and their level of associations was stable even when a new group was introduced. Penguins that had not yet established specific bonds with a particular individual or that had not yet selected their partner occupied the centres of both networks (Fig. 1a, b). The stable breeding pairs tended to stay more peripheral in the network and associated preferentially with familiar individuals (Fig. 1a, b). The observed higher association index between partners and their peripheral location in the network could be explained by penguins' specific breeding ecology (Borboroglu and Boersma, 2013; Favaro and Pichegru, 2017). Indeed, the special bond that partners establish over time greatly impacts their behaviours (Baciadonna et al., 2022, 2021). For example, when a partner was suddenly out of sight, in an expectancy violation paradigm, the focal penguin reacted faster to any call, almost five times faster when compared to a call emitted by a colony mate, due to an increased vigilance and arousal state caused by being separated from their relative partner (Baciadonna et al., 2021). Similarly, penguins' special bonds have an impact on vocal production, where partners are acoustically more similar to non-partner colony members (Baciadonna et al., 2022). The vocal accommodation phenomenon observed between partners is not caused simply by the greater interactions between individuals but, more likely, it results from the strong bond they establish and the higher arousal state when they hear each other's calls (Baciadonna et al., 2022).

African penguins are territorial (i.e., nest defence; Eggleton and Siegfried, 1979), monogamous and philopatric, with an extended breeding season (Smith, 2015). Although the peak of the breeding season occurs between February and July in the wild (Borboroglu and Boersma, 2013), in *ex-situ* colonies, these birds mate several times during the year (Figel et al., 2023). The lack of natural predators and abundance of food allow penguins to devote more time to mate, especially when they are in the reproductive stage of their lives (Figel et al., 2023). After several months in the open ocean, at the age of 3–6 years African penguins arrive at a terrestrial colony in the wild, when they are ready to mate (Sherley et al., 2017). On this occasion, new pairs form, and their bonds are reinforced before mating and preparing the nest. In zoos, the possibility of selecting a partner and mate is not restricted to a specific time of the year, allowing penguins, especially those not yet in a long-term relationship, to interact, establish new social bonds, and eventually mate. In this study, in a short period, the group of females introduced integrated with the non-partnered individuals of the existing colony, those most likely to establish new bonds (Fig. 1b).

Although we expected a greater occurrence of intersexual interactions compared to intrasexual interactions based on the importance of mate selection in this species, in both networks sex was not a predictor of the association preference observed in the colony. Contrary to the influence of sex, we identified the primary predictor of associations to be the time of arrival at the existing colony. Penguins arriving at the colony simultaneously exhibited a higher frequency of interactions. It's noteworthy that in our study, the two groups of penguins introduced prior to reaching the new colony were already familiar with each other as they



**Fig. 2. Percentage of time spent in dyadic interactions.** a) Network 1 (before 13/10/2021) from 24 individuals. Within the network 112 dyads were significantly associated and the breeding partners (colour coded) spent more than 40% of their time interacting with each other and b) Network 2 (after 13/10/2021) from 34 individuals. Within the network 212 dyads were significantly associated and the breeding partners (colour coded) spent over 30% of their time interacting with each other. In both figures the dyads were classified as associated if the observed SRI value was outside the 95% confidence interval of the distribution expected by chance – 1000 permutations. The dyadic association percentage in both graphs have been sorted from the highest percentage to the lowest.

shared the same colony beforehand. Interestingly, although in a different species, a controlled experiment on river otters (*Lontra canadensis*) showed that familiarity and past experiences were the main drivers of the formation of male groups (Hansen et al., 2009).

Likewise, the observed clustered networks may be attributed to the combination of arrival time and pre-existing familiarity before entering an established colony. To further investigate the factors that influence the formation of preferred associations within a colony, further studies are warranted. Promising candidates that might contribute to group formation include genetic relatedness and personality traits (Bos et al., 2016; Figel et al., 2023; Goumon et al., 2020; Hansen et al., 2009; Modesto et al., 2018; Pastorino et al., 2019; Traisnel and Pichgru, 2019). One limitation of this study stems from the relatively brief observation period of four months, potentially not fully capturing the behavioural variations influenced by seasonality. For instance, the dynamics of associations within a large captive flock of greater flamingos (*Phoenicopterus roseus*) were found to be influenced by the time of the observations (i.e., whether they were conducted during the breeding period or at other times; Rose and Croft, 2020, 2018). While the primary aim of this study was to investigate the short-term impact of introducing new individuals on the social dynamics of captive penguins, extending the data collection over multiple seasons and across different zoos would be highly valuable. Exploring these aspects would contribute to a more thorough understanding of how the previously highlighted factors can influence associations within the group. Additionally, it would serve to validate our results.

This study adds to the body of research demonstrating the role of SNA in assessing the impact of zoo management on social group structure and its potential impact on animal welfare (Koyama and Aureli, 2019; Less et al., 2010; Radosevich et al., 2021; Rose and Croft, 2017, 2015; Williams et al., 2020). The application of SNA has provided valuable input for maintaining appropriate living conditions by identifying strong bonds within a social group (Rose and Croft, 2015). Zoo management regimes that prevent animals from accessing their preferred social partners or which dismantle strong bonds can be detrimental to the entire group (group cohesion and group instability) and to the individual response to social stress. In our study, the breeding pairs were the core of the colony, and when under social changes, i.e. introducing members, their bonds were stable. Interestingly, the application of SNA in this short period of time has allowed us to identify a

potential new emerging breeding pair (individual H and I) who later mated and reproduced (personal communication from the penguins' keepers). Preserving these relationships is paramount when managing a breeding program or when moving some individuals to a different colony.

Introducing a group of animals that shared or lived in the same social group before being introduced to a new social group can speed up the process of integration within the existing group. The first six female penguins that were introduced integrated in less than two months with the existing colony (Network 1, Fig. 1a). Although we did not observe the same trend when the second group of ten penguins was introduced, it is likely that, given more time, the birds would have eventually integrated with the rest of the colony. In the wild, the formation of non-random associations between small groups of penguins (range five to ten) has been observed in the little penguin (*Eudyptula minor*) when arriving at or departing from a colony (Daniel et al., 2007). The synchronised parade shown by little penguins and the Adélie penguins (*Pygoscelis adeliae*) can be a strategy for diluting the likelihood of being predated (Daniel et al., 2007; Sladen, 1972). In addition, rockhopper (*Eudyptes chrysocome*), Adélie, and African penguins form small groups when foraging at sea (Sladen, 1972; Takahashi et al., 2004; Tremblay and Cherel, 1999; Wilson et al., 1986). The formation of small groups at sea reduces the risk of predation, allows coordination of the foraging activity by synchronising their diving, and increases efficiency in capturing prey (McInnes et al., 2017). Within the Zoom Torino colony, we have observed (L.B. and V.M. personal observations) that penguins engage in both synchronised parades and diving even in the presence of visitors (see also Ozella et al., 2015). Based on this evidence, we suggest that introducing small groups of familiar individuals with shared past experiences vs. a single penguin into an existing colony can encourage the expression of natural behaviours, such as exploratory and foraging activities, before integrating with the rest of colony members.

In conclusion, we showed that SNA can provide simple, fast, and ongoing representations of the social dynamics in colonial seabirds under human care, especially when social structures are artificially manipulated. Furthermore, SNA can provide practical advice for managing zoo animals, limiting the impact of translocation to a new social group on bird welfare and behaviour.

## CRedit authorship contribution statement

**Luigi Baciadonna:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Supervision, Visualization, Writing – original draft, Writing – review & editing. **Cristian Pasquaretta:** Formal analysis, Software, Visualization, Writing – review & editing. **Veronica Maraner:** Data curation, Writing – review & editing. **Valentina Isaja:** Data curation, Methodology, Writing – review & editing. **Livio Favaro:** Conceptualization, Funding acquisition, Methodology, Project administration, Resources, Supervision, Writing – original draft, Writing – review & editing.

## Declaration of Competing Interest

The authors have no competing interests to declare.

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