# Supplementary Material:

# Temporal dynamics of mother-offspring relationships in Bigg’s killer whales: opportunities for kin-directed help by post-reproductive females

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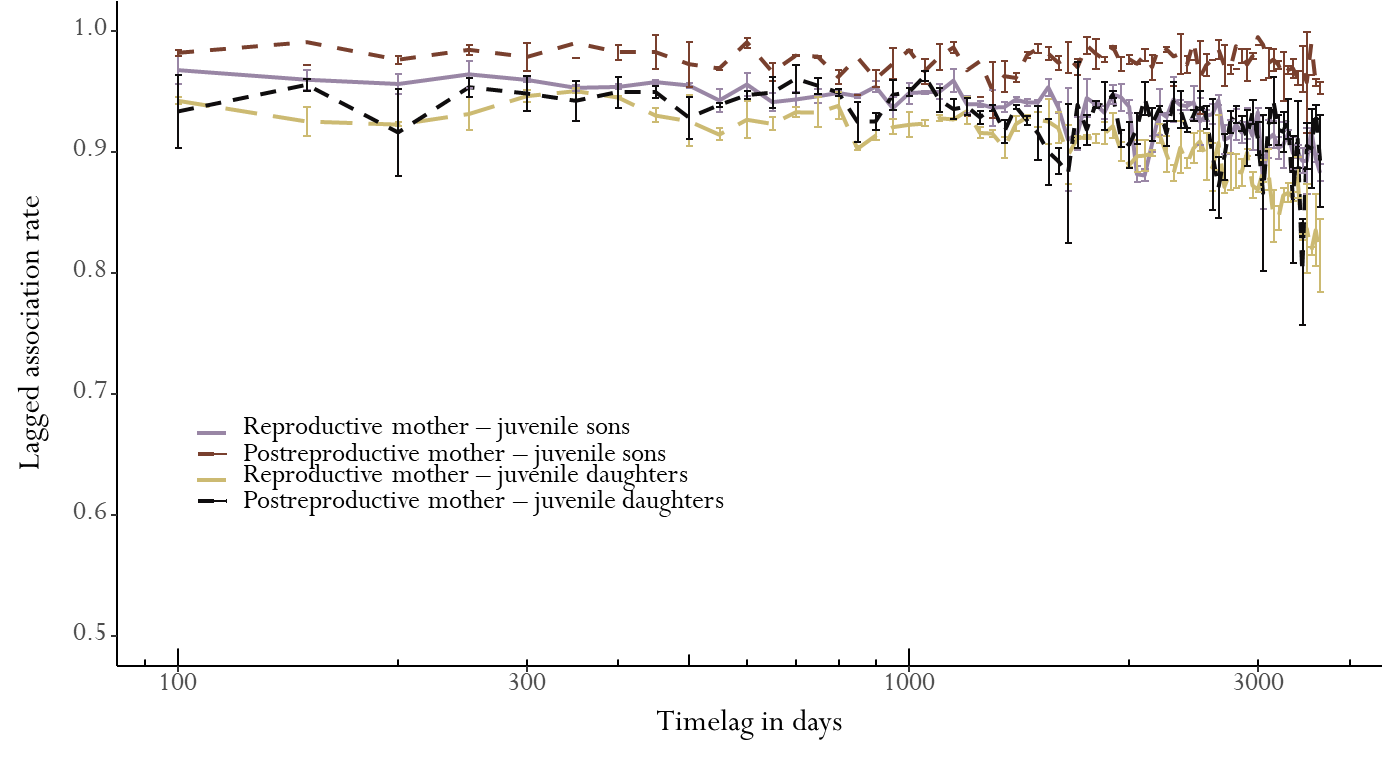
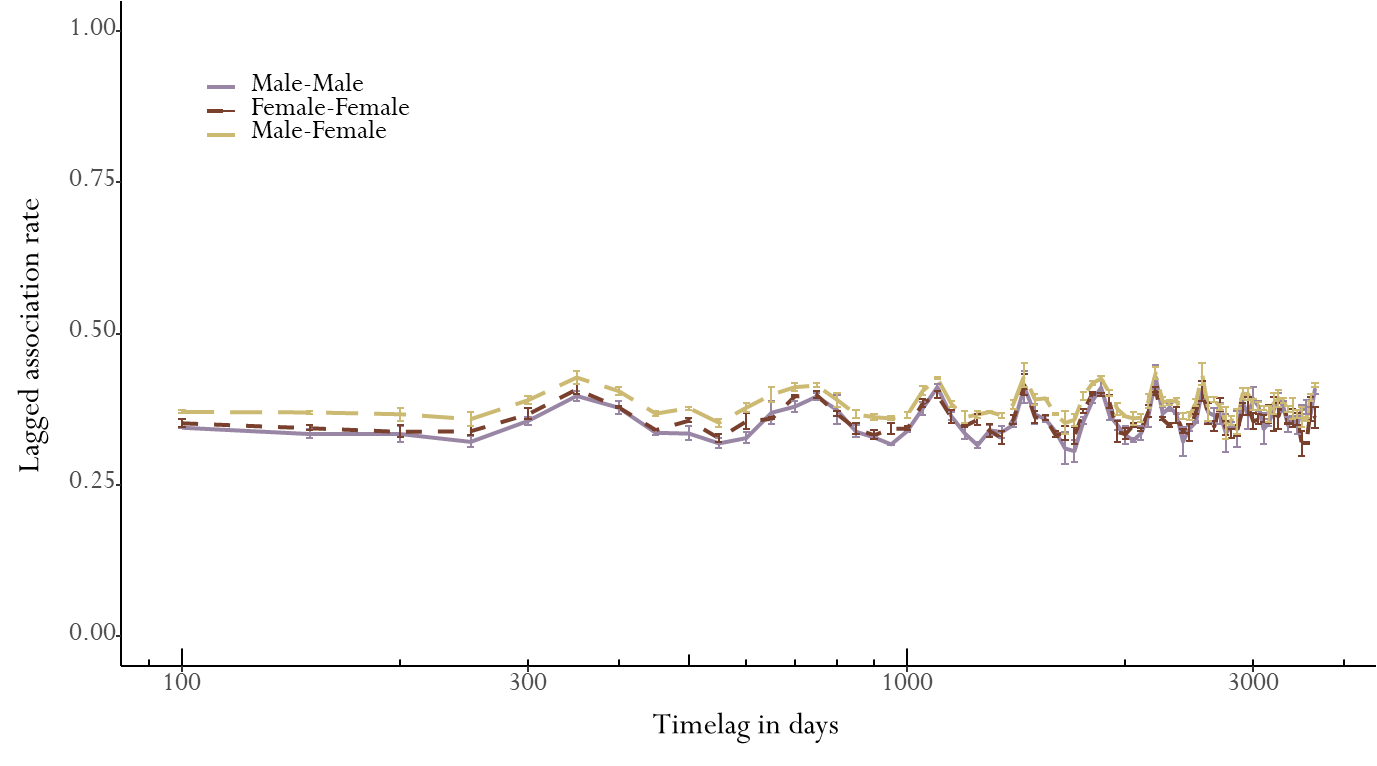
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Lagged association rates

Figure S1: Lagged association rate and jack-knife error over a maximum time lag of 10 years for associations between (A) male-male, female-female and male-female associations or (B) mothers and juvenile offspring and.



**A**

**B**

Binomial mixture model approach to identify social relationship categories

Binomial mixture models(1,2) were used to determine the distribution of the social relationships within Bigg’s killer whales. The model was tested for 2-5 social relationship components, which was applied to the observed association indices in each year of the data. We included three model fitting criteria Akaike’s Information Criterion (AIC), Bayesian Information Criterion (BIC) and Integrated Complete Likelihood (ICL) to evaluate the best fit model (from 2-9 social relationship components) for each year. The binomial mixture model indicate that the distribution of social relationships fall into 2-5 relationship components (1,2). The binomial mixture model was applied to association indices in each year in the data and the parsimony of each component model was evaluated across all years using the three model-fitting criteria. From this, all three model fit criteria suggested that 2 components is a good fit, and that as sampling effort increases both AIC and BIC suggest that more components are a better fit for the data. This is likely because more observations of more individuals lead to the observation of more rare or intermediate associations between individuals.

*Table S1: Differences in the different model fitting values for each year from the lowest value in a given year (best fit). Each row represents a model with the given number of components for the different fitting criteria (AIC, BIC, ICL). The best model based for each fitting criteria in a given year is indicated by grey shading.*

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | *AIC fit Criteria* | | | | *BIC fit Criteria* | | | | *ICL fit Criteria* | | | |
|  | *Number if components* | | | | *Number if components* | | | | *Number if components* | | | |
| *Year* | *2* | *3* | *4* | *5* | *2* | *3* | *4* | *5* | *2* | *3* | *4* | *5* |
| 1970 | 0 | 4 | 8 | 12 | 0 | 7 | 13 | 20 | 0 | 13 | 21 | 32 |
| 1974 | 0 | 4 | 8 | 12 | 0 | 6 | 11 | 17 | 0 | 9 | 18 | 22 |
| 1975 | 0 | 3 | 7 | 11 | 0 | 11 | 23 | 34 | 0 | 84 | 134 | 260 |
| 1976 | 0 | 4 | 8 | 12 | 0 | 9 | 17 | 26 | 0 | 42 | 70 | 92 |
| 1977 | 0 | 4 | 8 | 12 | 0 | 6 | 11 | 17 | 0 | 11 | 20 | 28 |
| 1978 | 0 | 4 | 8 | 12 | 0 | 9 | 18 | 28 | 0 | 42 | 61 | 89 |
| 1979 | 0 | 4 | 8 | 12 | 0 | 10 | 21 | 31 | 0 | 76 | 96 | 100 |
| 1980 | 0 | 4 | 8 | 12 | 0 | 13 | 25 | 38 | 0 | 266 | 326 | 547 |
| 1981 | 0 | 4 | 8 | 12 | 0 | 12 | 23 | 35 | 0 | 58 | 93 | 227 |
| 1982 | 0 | 4 | 8 | 12 | 0 | 12 | 23 | 35 | 0 | 116 | 67 | 288 |
| 1983 | 0 | 4 | 8 | 12 | 0 | 10 | 21 | 31 | 0 | 83 | 112 | 164 |
| 1984 | 0 | 4 | 8 | 12 | 0 | 15 | 30 | 45 | 0 | 515 | 1314 | 1492 |
| 1985 | 0 | 4 | 8 | 12 | 0 | 14 | 28 | 42 | 0 | 497 | 814 | 756 |
| 1986 | 3 | 0 | 4 | 8 | 0 | 8 | 24 | 39 | 0 | 235 | 1230 | 1789 |
| 1987 | 19 | 0 | 4 | 8 | 7 | 0 | 16 | 32 | 0 | 489 | 629 | 2088 |
| 1988 | 1 | 0 | 4 | 8 | 0 | 11 | 26 | 41 | 0 | 79 | 184 | 1275 |
| 1989 | 42 | 0 | 4 | 8 | 27 | 0 | 19 | 37 | 0 | 1666 | 6815 | 5796 |
| 1990 | 42 | 0 | 4 | 8 | 29 | 0 | 17 | 35 | 0 | 1259 | 3887 | 2814 |
| 1991 | 6 | 0 | 4 | 8 | 0 | 6 | 23 | 39 | 0 | 1034 | 1269 | 2728 |
| 1992 | 48 | 10 | 0 | 4 | 23 | 0 | 5 | 24 | 0 | 650 | 5148 | 6683 |
| 1993 | 92 | 0 | 4 | 8 | 78 | 0 | 18 | 35 | 0 | 884 | 1289 | 1545 |
| 1994 | 32 | 0 | 4 | 8 | 18 | 0 | 18 | 36 | 0 | 971 | 4593 | 6403 |
| 1995 | 52 | 0 | 4 | 8 | 38 | 0 | 18 | 35 | 0 | 549 | 2821 | 3437 |
| 1996 | 11 | 0 | 4 | 8 | 0 | 4 | 22 | 41 | 0 | 524 | 5582 | 8593 |
| 1997 | 0 | 4 | 3 | 7 | 0 | 18 | 32 | 50 | 0 | 3963 | 2217 | 5243 |
| 1998 | 0 | 4 | 8 | 12 | 0 | 17 | 34 | 50 | 0 | 2285 | 3625 | 4570 |
| 1999 | 31 | 0 | 4 | 8 | 16 | 0 | 19 | 38 | 0 | 485 | 680 | 10094 |
| 2000 | 203 | 0 | 4 | 8 | 188 | 0 | 19 | 39 | 0 | 190 | 4610 | 11409 |
| 2001 | 20 | 0 | 4 | 8 | 5 | 0 | 19 | 37 | 0 | 359 | 5626 | 6844 |
| 2002 | 0 | 4 | 7 | 11 | 0 | 18 | 36 | 55 | 0 | 4973 | 7943 | 9961 |
| 2003 | 141 | 1 | 0 | 4 | 123 | 0 | 15 | 35 | 0 | 6134 | 8101 | 11291 |
| 2004 | 97 | 31 | 0 | 4 | 65 | 14 | 0 | 20 | 0 | 996 | 1098 | 13014 |
| 2005 | 279 | 0 | 4 | 8 | 262 | 0 | 21 | 42 | 0 | 1737 | 19078 | 18484 |
| 2006 | 872 | 129 | 0 | 3 | 838 | 111 | 0 | 20 | 0 | 1076 | 17247 | 22542 |
| 2007 | 573 | 0 | 4 | 7 | 555 | 0 | 22 | 43 | 0 | 2654 | 17077 | 21713 |
| 2008 | 1206 | 165 | 0 | 1 | 1171 | 148 | 0 | 19 | 0 | 4802 | 7570 | 7737 |
| 2009 | 2581 | 282 | 66 | 0 | 2527 | 246 | 48 | 0 | 0 | 6199 | 8086 | 15745 |
| 2010 | 2589 | 145 | 0 | 0 | 2553 | 127 | 0 | 18 | 0 | 1284 | 2119 | 29881 |
| 2011 | 2033 | 402 | 60 | 0 | 1980 | 367 | 42 | 0 | 0 | 6313 | 12516 | 14285 |
| 2012 | 1668 | 134 | 16 | 0 | 1616 | 100 | 0 | 2 | 0 | 2694 | 4953 | 27560 |
| 2013 | 3515 | 188 | 38 | 0 | 3460 | 151 | 20 | 0 | 0 | 4452 | 11681 | 12712 |
| 2014 | 2306 | 82 | 2 | 0 | 2266 | 61 | 0 | 16 | 0 | 8206 | 22740 | 30228 |
| 2015 | 1490 | 121 | 28 | 0 | 1434 | 83 | 9 | 0 | 0 | 14117 | 24101 | 32108 |
| 2016 | 3212 | 444 | 10 | 0 | 3166 | 416 | 0 | 8 | 0 | 4284 | 20427 | 20957 |
| 2017 | 3536 | 367 | 117 | 0 | 3480 | 330 | 98 | 0 | 0 | 16747 | 18517 | 30476 |
| 2018 | 6429 | 725 | 105 | 0 | 6373 | 687 | 86 | 0 | 0 | 2617 | 16400 | 17375 |
| 2019 | 5325 | 438 | 78 | 0 | 5267 | 399 | 58 | 0 | 0 | 16919 | 18102 | 25129 |
| 2020 | 2867 | 184 | 18 | 0 | 2811 | 146 | 0 | 1 | 0 | 9398 | 11833 | 13600 |
| Count | 16 | 15 | 6 | 12 | 20 | 13 | 8 | 7 | 48 | 0 | 0 | 0 |

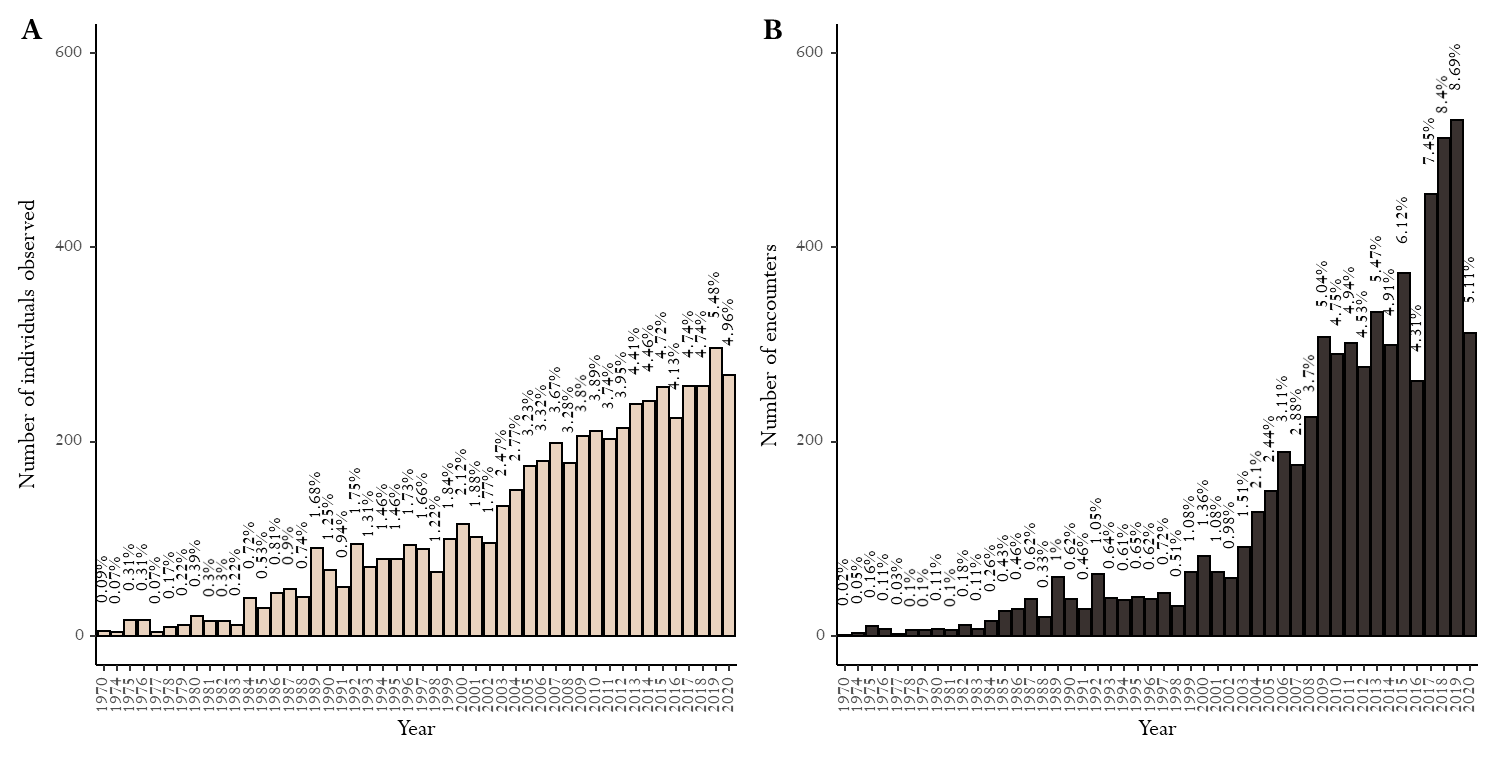


Figure S2: Yearly distribution of number of unique individuals observed (A) and number of unique encounters (B).

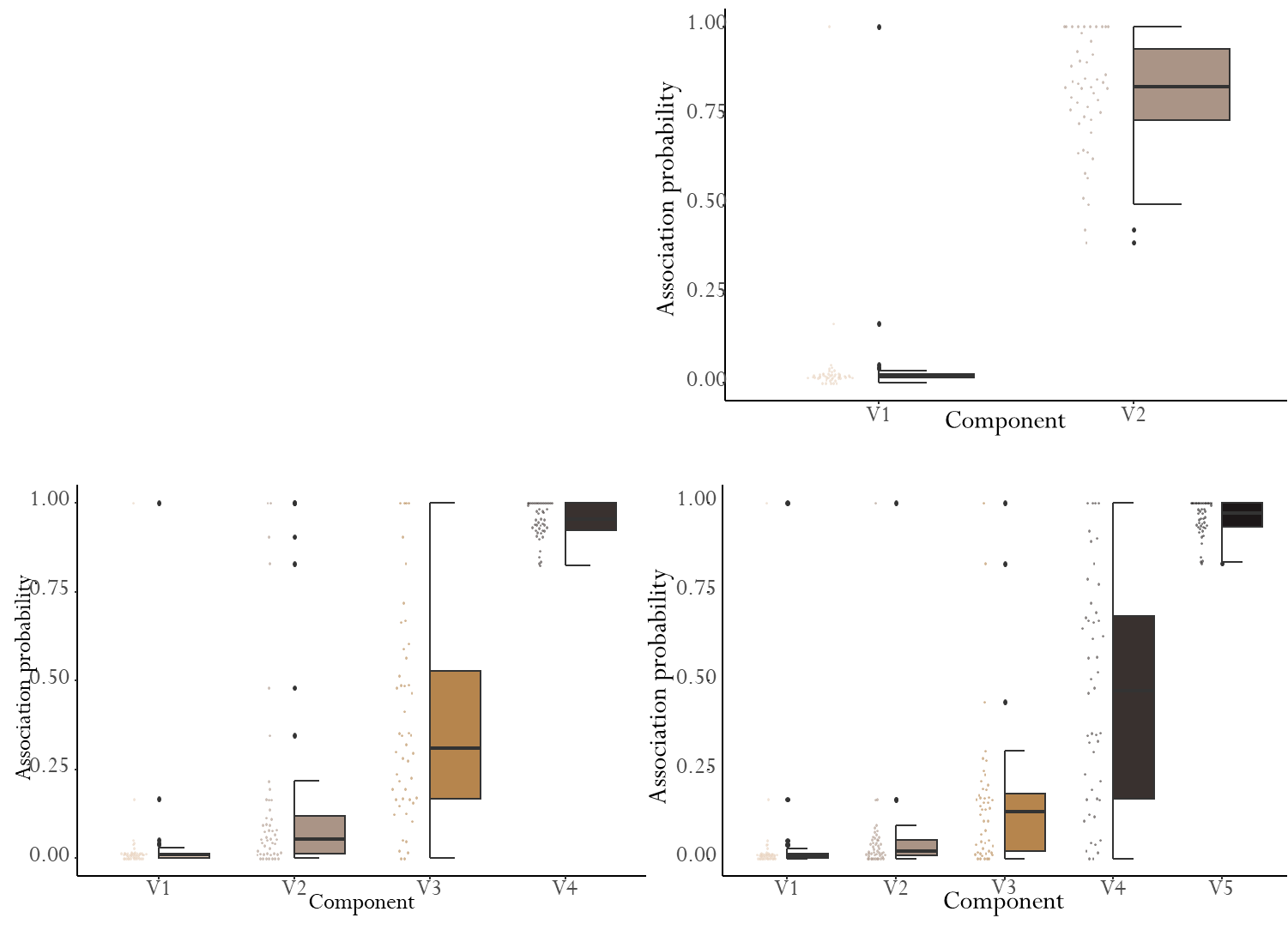
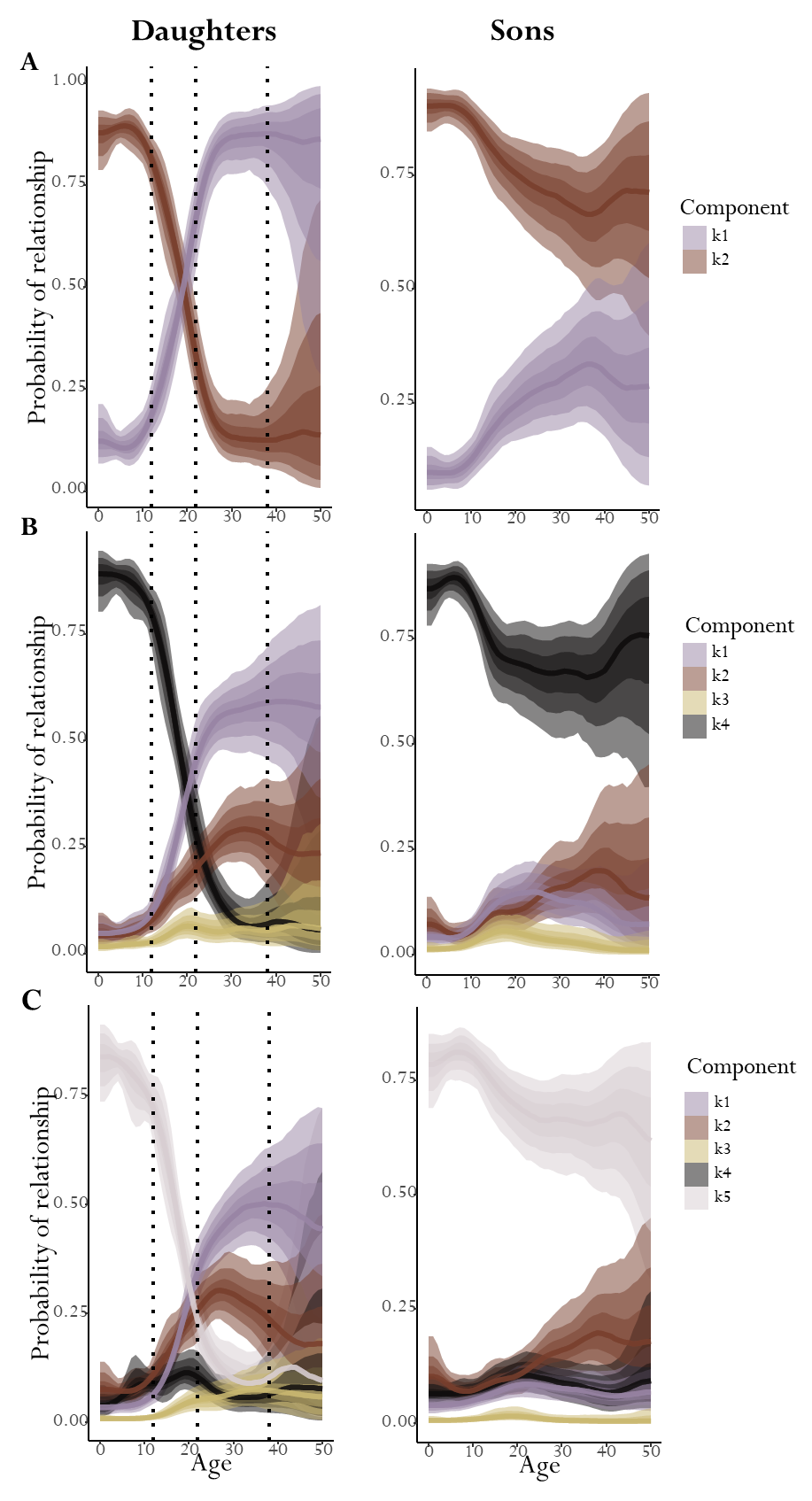


Figure S3: Barplot representing the mean and standard deviation (error bars) of the distribution of the association probability for models with (A) two components (V1-V2), (B) four components (V1-V4) and (C) five components (V1-V5) across the study period (1970-2020).

Figure S4: The probability of a mother-offspring association being classified in different components with offspring age for daughters (Left) and sons (Right). Lines represent the mean of the posterior distribution at each age and the darker and lighter shaded areas represents from darker to lighter shades the 50, 80 and 95% credible intervals, respectively (McElreath, 2019)(3). Vertical dotted lines in left side plots represent the ages at which 5, 50 and 95% of the female reproductive lifespan has occurred (Nielsen et al. 2021)(4). (A) is for 2 components ranging from weakest (K1) to strongest association (K2), (B) is for four components ranging from weakest (K1) to strongest association (K4), and (C) is for five components ranging from weakest (K1) to strongest association (K5).

Roving males

A number of males have been classified as ‘Roving males’ in the Bigg’s killer whales ecotype (N=8). These males were either observed as never or very rarely associating with their mother’s group (5).

Although there is no description in the literature or from observers on ‘Roving’ females, daughters may split from their mothers group following the birth of some of their offspring. This pattern can be seen in the relationship category between mother and daughter across daughter ages (Fig. S5).

Birth order

Here we have explored potential effect of birth order on our model. Out of all female and male offspring we see that daughters are likely to be in the weakest association with their mother regardless of birth order, while for males it is likely that they remain in the strongest association category with their mother regardless of birth order (Fig S6 and S7). It is important to note, however, only first born individuals are able to influence the model for offspring past the age of ~30 (Fig. S6). Modelling the probability of being in each of the three association categories as a function of offspring age and sex for first and later born offspring, show qualitatively similar patterns, but with more uncertainty for offspring of older ages of especially the later born individuals (Fig. S7).

Figure S5: The probability of daughters (left) and sons (right) being in a constant companion association with their mother for each individual daughter and son included in the analysis of temporal changes in association category plotted against the age of individuals. Darker shaded indicate a higher probability, while lighter shades indicate a weaker probability. Dashed red vertical lines indicate age 10 and 30 as these are the ages within which the model predicts the largest changes for daughters. Colours of son IDs indicate if sons have been categorised as lone (brown), permanently dispersed/Roving (red) or temporarily dispersed (magenta). These categories are based on observations, where lone is males that are observed on their own following the death of their mother. At the time of death of the mother these males are no longer included in the analysis. Temporary dispersal is males that are sometimes observed without their mother and permanently dispersed males are on most occasions observed without their mother.



Figure S6: The most likely association category between mother and daughters (A) or sons (B) for each individual daughter and son included in the analysis. Dashed red vertical lines indicate age 10 and 30 as these are the ages within which the model predicts the largest changes for daughters. Sons and daughters are grouped based on the birth order, so individuals in group 1 are first born, group 2 are second born and so on.

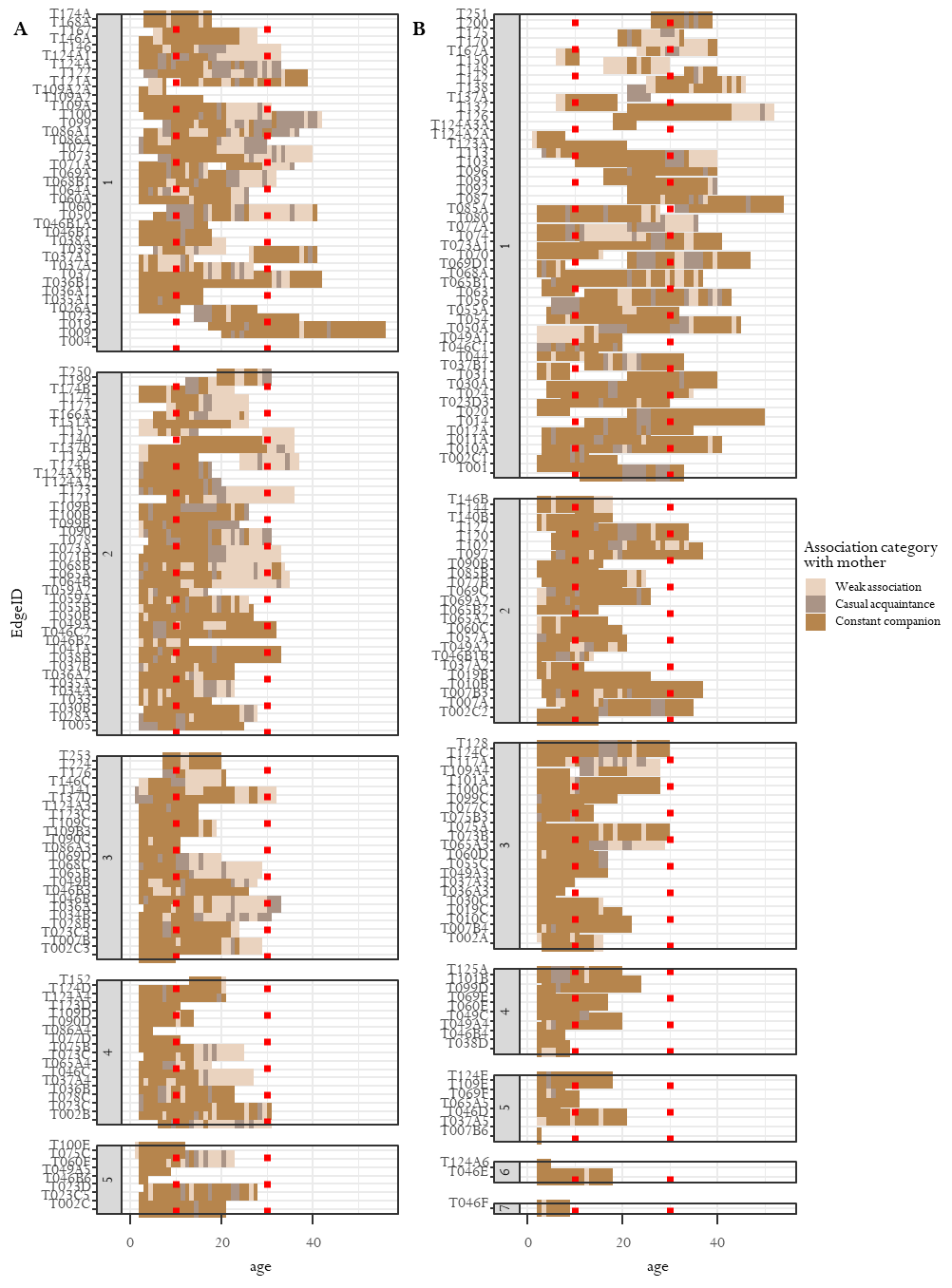
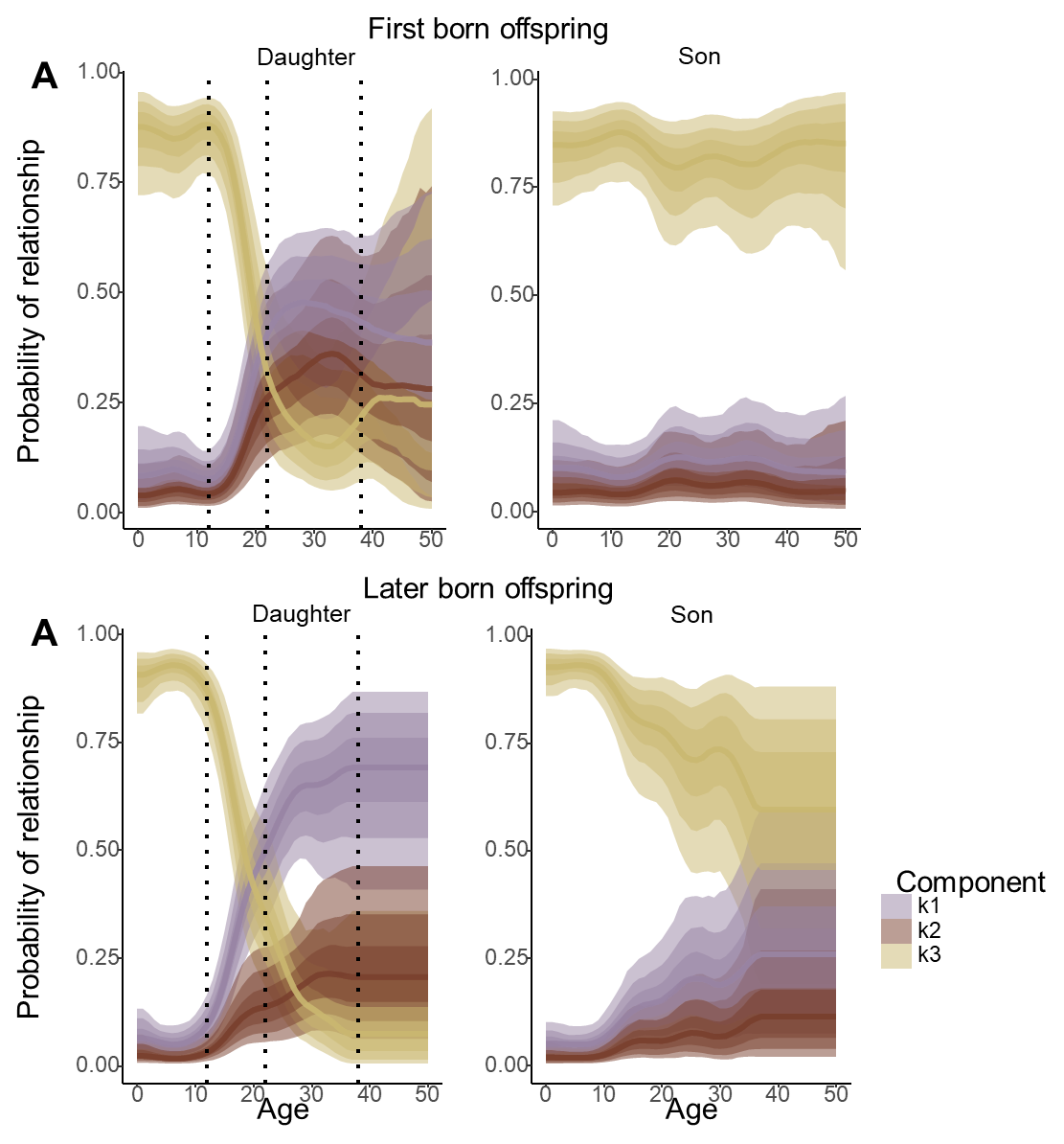


Figure S7: The probability of a mother-offspring association being classified in different components with offspring age for daughters (Left) and sons (Right), and for first born offspring (top, N= 1211) and later born offspring (bottom, N=2269). Lines represent the mean of the posterior distribution at each age and the darker and lighter shaded areas represents from darker to lighter shades the 50, 80 and 95% credible intervals, respectively (McElreath, 2019)(3). Vertical dotted lines in left side plots represent the ages at which 5, 50 and 95% of the female reproductive lifespan has occurred (Nielsen et al. 2021)(4).



# List of acknowledgements in alphabetic order

|  |
| --- |
| BC Cetacean Sightings Network |
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| Glacier Bay National Park |
| Island Adventures Whale Watching |
| Laskeek Bay Conservation Society |
| Marine Mammal Research Group |
| MERS Marine Education and Research Society |
| North Coast Cetacean Society |
| North Island Marine Mammal Stewardship Association |
| Ocean Wise |
| Orca Network |
| OrcaLab |
| Prince of Whales Whale Watching |
| Raincoast Research |
| Salmon Coast Field Station |
| Strawberry Island Marine Research Society |
| Stubbs Island Whale Watching |
| Tofino Whale Centre |
| University of Alaska Southeast |
| Vancouver Aquarium |

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