**Supplementary material**

**Survival improvements of marine mammals in zoological institutions mirror historical advances in human longevity**

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**Table S1.** Life expectancy and lifespan equality from one year of age for both sexes of harbour seal (*Phoca vitulina*), California sea lion (*Zalophus californianus*), polar bear (*Ursus maritimus*), and common bottlenose dolphin (*Tursiops truncatus*) for zoo-held and wild populations (Figures 2 and S5). Credible intervals could not be calculated for wild populations. The proportional relationship between the wild estimates and the mean estimates of the latest period (2005-2020) from ZIMS are depicted in the Improv. column. These are calculated as [*1+((value recent period–value oldest period)/value oldest)*] period for comparing periods, and [*1+((value zoo–value wild)/value wild)*] for comparison with the wild.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Species** | **Population** | **Sex** | **Period** | **N** | **Life expectancy (years)** | | | **Lifespan equality** | |
| **Mean** | **95%CI** | **Improv.** | **Mean** | **95%CI** |
| *P. vitulina* | Zoos | Female | 1877-1989 | 438 | 11.52 | 9.97;13.41 |  | 0.169 | -0.061;0.375 |
|  |  |  | 1990-2004 | 487 | 18.91 | 16.86;21.09 |  | 0.528 | 0.363;0.690 |
|  |  |  | 2005-2020 | 428 | 20.91 | 18.96;22.88 | 1.81 | 0.660 | 0.658;0.510 |
|  | Wild1 |  | 2002 | 1,003 | 7.04 |  | 2.97 | 0.539 |  |
|  | Wild2 |  | 2000-2007 | 166 | 8.76 |  | 2.39 | 0.174 |  |
|  | Zoos | Male | 1877-1989 | 353 | 11.27 | 9.57;13.25 |  | 0.113 | -0.104;0.313 |
|  |  |  | 1990-2004 | 424 | 16.31 | 14.29;18.50 |  | 0.406 | 0.234;0.571 |
|  |  |  | 2005-2020 | 386 | 19.02 | 16.93;21.15 | 1.69 | 0.574 | 0.398;0.748 |
|  | Wild1 |  | 2002 | 1,142 | 7.04 |  | 2.70 | 0.539 |  |
|  | Wild2 |  | 2000-2007 | 181 | 6.11 |  | 3.11 | -0.105 |  |
| *Z. californianus* | Zoos | Female | 1875-1974 | 692 | 6.05 | 5.36;6.76 |  | -0.045 | -0.147;0.054 |
|  |  |  | 1975-1989 | 737 | 11.39 | 10.41;12.46 |  | 0.272 | 0.161;0.371 |
|  |  |  | 1990-2004 | 788 | 16.21 | 15.12;17.28 |  | 0.746 | 0.632;0.862 |
|  |  |  | 2005-2020 | 832 | 18.17 | 17.20;19.10 | 3.00 | 0.986 | 0.862;1.108 |
|  | Wild3 |  | 1981-2006 | 94 | 11.00 |  | 1.65 | 0.423 |  |
|  | Wild4 |  | 1987-2015 | 6,833 | 5.75 |  | 3.16 | 0.290 |  |
|  | Zoos | Male | 1875-1974 | 514 | 4.69 | 4.04;5.37 |  | -0.140 | -0.261;-0.015 |
|  |  |  | 1975-1989 | 516 | 10.55 | 9.41;11.77 |  | 0.297 | 0.125;0.428 |
|  |  |  | 1990-2004 | 606 | 15.37 | 14.15;16.57 |  | 0.751 | 0.617;0.890 |
|  |  |  | 2005-2020 | 688 | 15.91 | 14.77;17.08 | 3.40 | 0.705 | 0.589;0.828 |
|  | Wild3 |  | 1981-2006 | 96 | 8.98 |  | 1.77 | 0.220 |  |
|  | Wild4 |  | 1987-2015 | 4,465 | 5.75 |  | 2.77 | 0.290 |  |
| *U. maritimus* | Zoos | Female | 1829-1974 | 569 | 22.68 | 21.00;24.40 |  | 0.947 | 0.735;1.144 |
|  |  |  | 1975-1989 | 512 | 20.02 | 18.16;21.89 |  | 0.664 | 0.499;0.829 |
|  |  |  | 1990-2004 | 355 | 21.29 | 19.28;23.13 |  | 0.981 | 0.772;1.188 |
|  |  |  | 2005-2020 | 243 | 25.08 | 23.17;26.75 | 1.11 | 1.407 | 1.162;1.638 |
|  | Wild5 |  | 1984-2011 | ~1,500 | 8.44 |  | 2.97 | 0.000 |  |
|  | Zoos | Male | 1829-1974 | 467 | 20.23 | 18.55;22.03 |  | 0.843 | 0.647;1.053 |
|  |  |  | 1975-1989 | 415 | 17.44 | 15.49;19.33 |  | 0.659 | 0.483;0.839 |
|  |  |  | 1990-2004 | 281 | 19.22 | 17.34;21.05 |  | 0.892 | 0.703;1.075 |
|  |  |  | 2005-2020 | 220 | 21.11 | 19.18;22.88 | 1.04 | 1.109 | 0.889;1.323 |
|  | Wild5 |  | 1984-2011 | ~1,500 | 7.04 |  | 3.00 | 0.142 |  |
| *T. truncatus* | Zoos | Female | 1947-1989 | 175 | 9.56 | 5.48;13.82 |  | -0.130 | -0.592;0.348 |
|  |  |  | 1990-2004 | 236 | 25.66 | 21.72;30.01 |  | 0.738 | 0.378;1.067 |
|  |  |  | 2005-2020 | 301 | 30.68 | 26.73;35.25 | 3.21 | 0.748 | 0.439;1.008 |
|  | Wild6 |  | 1978-1997 | 78 | 8.63 |  | 3.55 | 0.172 |  |
|  | Wild7 |  | 1986-2003 | 42 | 9.48 |  | 3.24 | 0.319 |  |
|  | Zoos | Male | 1947-1989 | 138 | 9.44 | 6.66;12.32 |  | -0.030 | -0.366;0.276 |
|  |  |  | 1990-2004 | 205 | 20.88 | 16.84;15.68 |  | 0.428 | 0.026;0.711 |
|  |  |  | 2005-2020 | 271 | 30.22 | 24.37;41.50 | 3.20 | 0.459 | 0.011;0.800 |
|  | Wild6 |  | 1978-1997 | 125 | 9.33 |  | 3.24 | 0.279 |  |
|  | Wild7 |  | 1986-2003 | 69 | 9.48 |  | 3.19 | 0.319 |  |

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**Table S2.** Proportional hazards effects of wild-born origin on survival. We provide the mean estimates, their standard errors (SE), and the lower and upper 95% credible intervals. Bayesian survival trajectory analyses were conducted on each sex and species for individuals in zoological institutions between 1990 and 2020. The potential scale reduction factor (PSRF) is an estimated factor by which the scale of the distribution for the target distribution might be reduced if the simulations were continued for an infinite number of iterations; PSRF declines to 1 as the number of iterations approaches infinity.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Species** | **Sex** | **Mean** | **SE** | **2.50%** | **97.50%** | **PSRF** |
| Harbour seal | Female | -0.205 | 0.161 | -0.519 | 0.106 | 1.007 |
| *Phoca vitulina* | Male | 0.301 | 0.167 | -0.037 | 0.611 | 1.008 |
| California sea lion | Female | -0.003 | 0.108 | -0.222 | 0.212 | 1.000 |
| *Zalophus californianus* | Male | 0.086 | 0.139 | -0.194 | 0.348 | 1.000 |
| Polar bear | Female | -0.253 | 0.143 | -0.535 | 0.025 | 1.000 |
| *Ursus maritimus* | Male | -0.322 | 0.177 | -0.666 | 0.018 | 1.000 |
| Common bottlenose dolphin | Female | 0.751 | 0.231 | 0.304 | 1.211 | 1.018 |
| *Tursiops truncatus* | Male | 0.838 | 0.208 | 0.433 | 1.240 | 1.001 |

**Table S3.** Calibrated Kulback-Leibler discrepancies between the posterior densities of life expectancy and lifespan equality in the last period (2005-2020) and those of the previous periods for all four species. A value of 0 implies that the two distributions are identical, and a value of 1 implies that they are entirely different (complete information loss if we use the posterior density from the previous periods to predict that of the last period). As a reference, values below 0.25 are highlighted in boldface. Survival analyses were carried out from birth (Fig. S3), from age one (Fig. S4), and from age at sexual maturity (Fig. S5).

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Analysis from** | **Variable** | **Sex** | **Species** | **< 1975** | **< 1990 or**  **1975-1989** | **1990-2004** |
| **birth** | Life exp. | Female | *Phoca vitulina* | - | 1 | 0.96 |
|  |  |  | *Zalophus californianus* | 1 | 1 | 1 |
|  |  |  | *Ursus maritimus* | 1 | 1 | 1 |
|  |  |  | *Tursiops truncatus* | - | 1 | 0.99 |
|  |  | Male | *Phoca vitulina* | - | 1 | 1 |
|  |  |  | *Zalophus californianus* | 1 | 1 | 0.98 |
|  |  |  | *Ursus maritimus* | 1 | 1 | 0.98 |
|  |  |  | *Tursiops truncatus* | - | 1 | 1 |
|  | Lifesp. eq. | Female | *Phoca vitulina* | - | 1 | 0.83 |
|  |  |  | *Zalophus californianus* | 1 | 1 | 1 |
|  |  |  | *Ursus maritimus* | 1 | 1 | 1 |
|  |  |  | *Tursiops truncatus* | - | 1 | 0.76 |
|  |  | Male | *Phoca vitulina* | - | 1 | 1 |
|  |  |  | *Zalophus californianus* | 1 | 1 | 0.86 |
|  |  |  | *Ursus maritimus* | 1 | 1 | 0.97 |
|  |  |  | *Tursiops truncatus* | - | 0.89 | 0.64 |
| **age one** | Life exp. | Female | *Phoca vitulina* | - | 1 | 0.87 |
|  |  |  | *Zalophus californianus* | 1 | 1 | 1 |
|  |  |  | *Ursus maritimus* | 0.97 | 1 | 1 |
|  |  |  | *Tursiops truncatus* | - | 1 | 0.91 |
|  |  | Male | *Phoca vitulina* | - | 1 | 0.96 |
|  |  |  | *Zalophus californianus* | 1 | 1 | 0.35 |
|  |  |  | *Ursus maritimus* | 0.35 | 1 | 0.86 |
|  |  |  | *Tursiops truncatus* | - | 1 | 0.93 |
|  | Lifesp. eq. | Female | *Phoca vitulina* | - | 1 | 0.77 |
|  |  |  | *Zalophus californianus* | 1 | 1 | 1 |
|  |  |  | *Ursus maritimus* | 1 | 1 | 1 |
|  |  |  | *Tursiops truncatus* | - | 1 | **0.03** |
|  |  | Male | *Phoca vitulina* | - | 1 | 0.83 |
|  |  |  | *Zalophus californianus* | 1 | 1 | 0.26 |
|  |  |  | *Ursus maritimus* | 0.94 | 1 | 0.86 |
|  |  |  | *Tursiops truncatus* | - | 0.91 | **0.10** |
| **age at** | Life exp. | Female | *Phoca vitulina* | - | 1 | 0.95 |
| **sexual** |  |  | *Zalophus californianus* | 1 | 1 | 1 |
| **maturity** |  |  | *Ursus maritimus* | 0.72 | 1 | 1 |
|  |  |  | *Tursiops truncatus* | - | 1 | 0.87 |
|  |  | Male | *Phoca vitulina* | - | 1 | 0.97 |
|  |  |  | *Zalophus californianus* | 1 | 1 | 0.39 |
|  |  |  | *Ursus maritimus* | **0.11** | 1 | 0.90 |
|  |  |  | *Tursiops truncatus* | - | 1 | 0.90 |
|  | Lifesp. eq. | Female | *Phoca vitulina* | - | 1 | 0.77 |
|  |  |  | *Zalophus californianus* | 1 | 1 | 1 |
|  |  |  | *Ursus maritimus* | 1 | 1 | 0.99 |
|  |  |  | *Tursiops truncatus* | - | 0.66 | **0.01** |
|  |  | Male | *Phoca vitulina* | - | 1 | 0.96 |
|  |  |  | *Zalophus californianus* | 1 | 1 | 0.51 |
|  |  |  | *Ursus maritimus* | 0.99 | 1 | 0.94 |
|  |  |  | *Tursiops truncatus* | - | 0.57 | **0.10** |

**Table S4.** Calibrated Kullback-Leibler discrepancies (K-L) between the life expectancy and lifespan equality posterior densities of females and that of males from age one (see Figure S8). The K-L values measure the loss of information if we were to predict the female posterior density from the male’s. These K-L values are standardised such that a value of 0 implies that both posterior densities are equal, and 1.00 that they are entirely different. As a reference, values below 0.25 are highlighted in boldface.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Species** | **Variable** | **< 1975** | **< 1990 or**  **1975-1989** | **1990-2004** | **2005-2020** |
| *Phoca vitulina* | Life expectancy | - | **0.04** | 0.94 | 0.83 |
|  | Lifespan equality | - | **0.11** | 0.65 | 0.46 |
| *Zalophus californianus* | Life expectancy | 1.00 | 0.72 | 0.69 | 1.00 |
|  | Lifespan equality | 0.83 | **0.22** | **0.03** | 1.00 |
| *Ursus maritimus* | Life expectancy | 0.98 | 0.97 | 0.90 | 1.00 |
|  | Lifespan equality | 0.39 | **0.01** | 0.30 | 0.95 |
| *Tursiops truncatus* | Life expectancy | - | **0.13** | 0.91 | 0.49 |
|  | Lifespan equality | - | **0.19** | 0.79 | 0.88 |

**Table S5.** Quantile of the wild value on the posterior densities of life expectancy (Life expect.) and lifespan equality (Lifesp. eq.) for all periods for the analyses from age one and from age at sexual maturity. In bold, we highlighted values outside the 95% credible intervals. We italicised values below the lower 95% credible interval, indicating that the value obtained for the wild population falls on the lower end of the posterior distribution, and can therefore be assumed to be considerably lower than the posterior density average from the ZIMS population for the given period.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Analysis from** | **Species** | **Sex** | **Variable** | **Study** | **< 1975** | **< 1990 or 1975-1989** | **1990-2004** | **2005-2020** |
| Age one | *P. vitulina* | Female | Life exp. | Harkonen (2007) | - | ***< 0.001*** | ***< 0.001*** | ***< 0.001*** |
|  |  |  |  | Hasting (2012) | - | ***< 0.001*** | ***< 0.001*** | ***< 0.001*** |
|  |  |  | Lifesp. eq. | Harkonen (2007) | - | **0.999** | 0.555 | 0.060 |
|  |  |  |  | Hasting (2012) | - | 0.517 | ***< 0.001*** | ***< 0.001*** |
|  |  | Male | Life exp. | Harkonen (2007) | - | ***< 0.001*** | ***< 0.001*** | ***< 0.001*** |
|  |  |  |  | Hasting (2012) | - | ***< 0.001*** | ***< 0.001*** | ***< 0.001*** |
|  |  |  | Lifesp. eq. | Harkonen (2007) | - | **1.000** | **0.936** | 0.345 |
|  |  |  |  | Hasting (2012) | - | ***0.022*** | ***< 0.001*** | ***< 0.001*** |
|  | *Z. californianus* | Female | Life exp. | Hernandez (2008) | 1 | 0.229 | ***< 0.001*** | ***< 0.001*** |
|  |  |  |  | Delong (2017) | 0.205 | ***< 0.001*** | ***< 0.001*** | ***< 0.001*** |
|  |  |  | Lifesp. eq. | Hernandez (2008) | 1 | **0.997** | ***< 0.001*** | ***< 0.001*** |
|  |  |  |  | Delong (2017) | 1 | 0.631 | ***< 0.001*** | ***< 0.001*** |
|  |  | Male | Life exp. | Hernandez (2008) | 1 | ***0.005*** | ***< 0.001*** | ***< 0.001*** |
|  |  |  |  | Delong (2017) | 0.999 | ***< 0.001*** | ***< 0.001*** | ***< 0.001*** |
|  |  |  | Lifesp. eq. | Hernandez (2008) | 1 | 0.156 | ***< 0.001*** | ***< 0.001*** |
|  |  |  |  | Delong (2017) | 1 | 0.461 | ***< 0.001*** | ***< 0.001*** |
|  | *U. maritimus* | Female | Life exp. | Lunn (2016) | < 0.001 | ***< 0.001*** | ***< 0.001*** | ***< 0.001*** |
|  |  |  | Lifesp. eq. | Lunn (2016) | < 0.001 | ***< 0.001*** | ***< 0.001*** | ***< 0.001*** |
|  |  | Male | Life exp. | Lunn (2016) | < 0.001 | ***< 0.001*** | ***< 0.001*** | ***< 0.001*** |
|  |  |  | Lifesp. eq. | Lunn (2016) | < 0.001 | ***< 0.001*** | ***< 0.001*** | ***< 0.001*** |
|  | *T. truncatus* | Female | Life exp. | StolenBarlow (2003) | - | 0.336 | ***< 0.001*** | ***< 0.001*** |
|  |  |  |  | Mattson (2006) | - | 0.487 | ***< 0.001*** | ***< 0.001*** |
|  |  |  | Lifesp. eq. | StolenBarlow (2003) | - | 0.889 | ***< 0.001*** | ***< 0.001*** |
|  |  |  |  | Mattson (2006) | - | **0.965** | ***0.009*** | ***0.002*** |
|  |  | Male | Life exp. | StolenBarlow (2003) | - | 0.469 | ***< 0.001*** | ***< 0.001*** |
|  |  |  |  | Mattson (2006) | - | 0.512 | ***< 0.001*** | ***< 0.001*** |
|  |  |  | Lifesp. eq. | StolenBarlow (2003) | - | **0.971** | 0.174 | 0.205 |
|  |  |  |  | Mattson (2006) | - | **0.984** | 0.245 | 0.260 |
| age at | *P. vitulina* | Female | Life exp. | Harkonen (2007) | - | ***< 0.001*** | ***< 0.001*** | ***< 0.001*** |
| sexual |  |  |  | Hasting (2012) | - | ***< 0.001*** | ***< 0.001*** | ***< 0.001*** |
| maturity |  |  | Lifesp. eq. | Harkonen (2007) | - | **0.970** | 0.139 | ***0.002*** |
|  |  |  |  | Hasting (2012) | - | 0.469 | ***< 0.001*** | ***< 0.001*** |
|  |  | Male | Life exp. | Harkonen (2007) | - | ***< 0.001*** | ***< 0.001*** | ***< 0.001*** |
|  |  |  |  | Hasting (2012) | - | ***< 0.001*** | ***< 0.001*** | ***< 0.001*** |
|  |  |  | Lifesp. eq. | Harkonen (2007) | - | **0.974** | 0.510 | ***0.006*** |
|  |  |  |  | Hasting (2012) | - | 0.455 | ***0.003*** | ***< 0.001*** |
|  | *Z. californianus* | Female | Life exp. | Hernandez (2008) | 1 | **0.968** | ***< 0.001*** | ***< 0.001*** |
|  |  |  |  | Delong (2017) | 0.002 | ***< 0.001*** | ***< 0.001*** | ***< 0.001*** |
|  |  |  | Lifesp. eq. | Hernandez (2008) | 1 | **1.000** | ***0.022*** | ***< 0.001*** |
|  |  |  |  | Delong (2017) | 1 | **1.000** | ***0.037*** | ***< 0.001*** |
|  |  | Male | Life exp. | Hernandez (2008) | 1 | ***0.044*** | ***< 0.001*** | ***< 0.001*** |
|  |  |  |  | Delong (2017) | 0.433 | ***< 0.001*** | ***< 0.001*** | ***< 0.001*** |
|  |  |  | Lifesp. eq. | Hernandez (2008) | 1 | 0.474 | ***< 0.001*** | ***< 0.001*** |
|  |  |  |  | Delong (2017) | 1 | **1.000** | 0.172 | 0.475 |
|  | *U. maritimus* | Female | Life exp. | Lunn (2016) | < 0.001 | ***< 0.001*** | ***< 0.001*** | ***< 0.001*** |
|  |  |  | Lifesp. eq. | Lunn (2016) | < 0.001 | ***< 0.001*** | ***< 0.001*** | ***< 0.001*** |
|  |  | Male | Life exp. | Lunn (2016) | < 0.001 | ***< 0.001*** | ***< 0.001*** | ***< 0.001*** |
|  |  |  | Lifesp. eq. | Lunn (2016) | < 0.001 | ***< 0.001*** | ***< 0.001*** | ***< 0.001*** |
|  | *T. truncatus* | Female | Life exp. | StolenBarlow (2003) | - | ***0.003*** | ***< 0.001*** | ***< 0.001*** |
|  |  |  |  | Mattson (2006) | - | ***< 0.001*** | ***< 0.001*** | ***< 0.001*** |
|  |  |  | Lifesp. eq. | StolenBarlow (2003) | - | 0.594 | 0.145 | 0.107 |
|  |  |  |  | Mattson (2006) | - | 0.122 | ***0.011*** | ***0.006*** |
|  |  | Male | Life exp. | StolenBarlow (2003) | - | ***0.039*** | ***< 0.001*** | ***< 0.001*** |
|  |  |  |  | Mattson (2006) | - | ***0.010*** | ***< 0.001*** | ***< 0.001*** |
|  |  |  | Lifesp. eq. | StolenBarlow (2003) | - | **0.950** | 0.394 | 0.471 |
|  |  |  |  | Mattson (2006) | - | 0.747 | 0.106 | 0.223 |

**Table S6.** Summary of changes in zoological institutions management practices for the harbour seal (*Phoca vitulina*), California sea lion (*Zalophus californianus*), polar bear (*Ursus maritimus*), and common bottlenose dolphin (*Tursiops truncatus*), documented from the literature and workshop sessions gathering experts of the four studied species (on 2nd, 7th and 14th of December 2021).

|  |  |  |
| --- | --- | --- |
| **Description of management change** | **Year** | **Species** |
| **Legislation and zoo & aquarium associations** |  |  |
| Creation of the Association of Zoos & Aquariums (AZA) | 1924 | All |
| Creation of the World Association of Zoos & Aquariums (WAZA) | 1935 | All |
| Creation of the Japanese Association of Zoos & Aquariums (JAZA) | 1939 | All |
| Passing of the Animal Welfare Act (USA) | 1966 | All |
| Creation of the British and Irish Association of Zoos and Aquariums (BIAZA) | 1966 | All |
| Passing of the Marine Mammal Protection Act (USA) | 1972 | All |
| Establishment of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) | 1975 | Polar bear, Appendix II (1996)  Common bottlenose dolphin, Appendix II (2003) |
| Creation of the Southeast Asian Zoo Association (SEAZA) | 1990 | All |
| Creation of the Zoos & Aquariums Association (ZAA) | 1990 | All |
| Creation of the European Association of Zoos & Aquaria (EAZA) | 1992 | All |
| Passing of the Polar Bear Protection Act (Canada) | 2002 | Polar bear |
| Import ban for cetaceans (Switzerland) | 2012 | Common bottlenose dolphin |
| Ban on captive cetaceans (Canada) | 2019 | Common bottlenose dolphin |
| Ban on show cetaceans (France) | 2021 | Common bottlenose dolphin |
| **Guidelines** |  |  |
| AZA accreditation starts | 1974 | All |
| AZA develop SSP | 1983 | All |
| Creation of the 19 first EEPs (Europe) | 1985 | All |
|  | 1994 | Common bottlenose dolphin |
|  | 2006 | Polar bear |
| EAZA first guidelines | 1992 | California sealion |
|  | 1994 | Common bottlenose dolphin |
|  | 2006 | Polar bear |
| Creation of the Alliance of Marine Mammal Parks & Aquariums (AMMPA) | 1998 | All |
| AMMPA accreditation starts | 2000 | All |
| AZA enrichment is mandatory | 2000 | All |
| Studbook | 2006 | Polar bear |
| EAZA Best Practices Guidelines 1st Edition | 2018 |  |
| **Veterinary medicine** |  |  |
| Creation of the International Association for Aquatic Animal Medicine (IAAAM) | 1969 |  |
| Creation of the International Marine Animal Trainers’ Association (IMATA) | 1972 |  |
| Gradual improvements in marine mammal veterinary medicine1,2 | 1970s onwards | All |
| Improvement of anaesthetic protocols1,3 | 1970s onwards | Harbour seal  California sealion  Common bottlenose dolphin |
| Voluntary participation of animals in routine examinations  First voluntary polar bear blood sample | 1990s onwards  2002 | All |
| Installation of lifting pool floors to restrain and treat bottlenose dolphins (especially in medical and nursery pools) | Mid-1990s | Common bottlenose dolphin |
| China increases the number of vets in zoos | 2000s onwards | All |
| **Nutrition** |  |  |
| Diets improved by accounting for the nutritional requirements for different species, sexes, and life stages14,15,41 | 1990s onwards | All |
| Improved defrosting protocols, food preparation methods, sourcing of human-grade food products, vitamin supplementation, and delivery of food through training and enrichment | 1990s onwards | All |
| **Habitat** |  |  |
| High point of view in the enclosure4 | 2010s | Polar bear |
| Not only concrete but also soil4 | 2010s | Polar bear |
| Colour of the pool, salinity, shield from sun5 | 2010s | Pinnipeds |

**References:**

1. *CRC Handbook of Marine Mammal Medicine*. (CRC Press, 2018).
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**Chart

Description automatically generated**

**Figure S1.** Records of the number of individuals for each marine mammal species present in the Species360 Zoological Information Management System. The California sea lion (*Zalophus californianus*, **1.00**), harbour seal (*Phoca vitulina*, **2**), common bottlenose dolphin (*Tursiops truncatus*, **3**), and polar bear (*Ursus maritimus*¸**4**) collectively represent 63.4% of all marine mammals recorded since the early 1800s.

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**Figure S2.** Distribution of the age at last observation (i.e., death or last detection) per species and sex, including unknown sexed individuals, for individuals recorded in the ZIMS database. The vertical red dashed line indicates the upper 99% cut-off, after which records were not included in the survival analyses. For display purposes, we limited the age range for the unknown sex individuals to 20 years since most records occurred within this window, while the y-axis in all plots was truncated at 50.

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**Figure S3.** Posterior distribution of the mortality probability between birth and age one across time in zoological institutions for females and males of the four marine mammal species included in the study. The shaded polygons indicate the 95% credible intervals.

**Chart, bar chart, histogram

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**Figure S4.** Number and percentage of individuals living in zoological institutions born in the wild (dark blue), in zoos (light blue), or with birth sites not recorded (light grey) per species and period.

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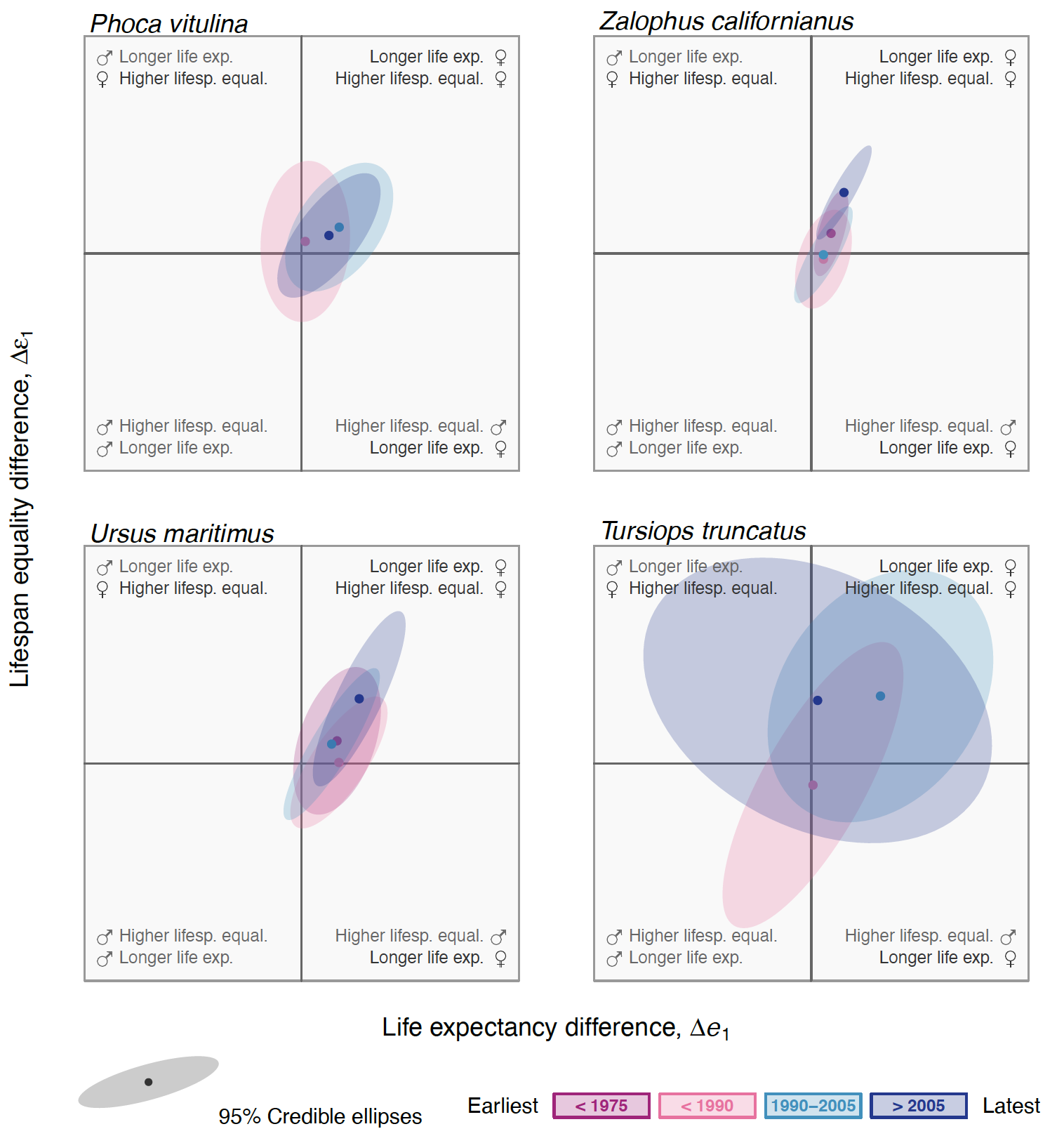
**Figure S5.** Life expectancy and lifespan equality from birth across time for both sexes of zoo-held populations of the four marine mammal species included in the study. The dots represent the mean values, while the size and shape of the ellipses represent the 95% confidence interval. Distributions on the top and left sides indicate the univariate posterior distributions of life expectancy and lifespan equality, respectively. Sample sizes are shown in Table S1. Kulback-Leibler values between periods using the recent period as a reference for each sex and species are shown in Table S3.

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**Figure S6.** Life expectancy and lifespan equality from age one across time for both sexes of zoo-held populations of the four marine mammal species included in the study. The dots represent the mean values, while the size and shape of the ellipses represent the 95% confidence interval. Distributions on the top and left sides indicate the univariate posterior distributions of life expectancy and lifespan equality, respectively. Sample sizes are shown in Table S1. Kulback-Leibler values between periods using the recent period as a reference for each sex and species are shown in Table S3.

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**Figure S7.** Remaining life expectancy and lifespan equality from age at sexual maturity across time for both sexes of zoo-held populations of the four marine mammal species included in the study. The dots represent the mean values, while the size and shape of the ellipses represent the 95% confidence interval. Distributions on the top and left sides indicate the univariate posterior distributions of life expectancy and lifespan equality, respectively. Sample sizes are shown in Table S1. Kulback-Leibler values between periods using the recent period as a reference for each sex and species are shown in Table S3.



**Figure S8.** Changes in sex differences in remaining life expectancy and lifespan equality from one year of age across time for both sexes of zoo-held harbour seal (*Phoca vitulina*), California sea lion (*Zalophus californianus*), polar bear (*Ursus maritimus*), and common bottlenose dolphin (*Tursiops truncatus*). Sample sizes are shown in Table S1. Kulback-Leibler values between sexes for each period and species are shown in Table S4.