Evaluation of population health among bottlenose dolphins (Tursiops truncatus) at the United States Navy Marine Mammal Program

Stephanie K. Venn-Watson, DVM, MPH; Eric D. Jensen, DVM; Sam H. Ridgway, DVM, PhD, DACZVM

Objective—To evaluate health indicators for a population of bottlenose dolphins in the US Navy Marine Mammal Program (MMP) by use of data acquired from 1988 through 2007.

Design—Retrospective cohort study.

Animals—167 bottlenose dolphins.

Procedures—The following indicators were used to evaluate the health of dolphins during the 20-year period: 5-year age structure, median survival age, annual survival rates, mortality rates, and neonatal and calf survival and mortality rates. Limitations of these population measurements as health indicators for dolphins were assessed.

Results—Crude mortality rates of dolphins for 1988 through 1992, 1993 through 1997, 1998 through 2002, and 2003 through 2007 were 3.1%, 4.7%, 3.6%, and 2.4%, respectively; during these same 4 study periods, median survival ages were 14.3, 14.4, 17.7, and 26.1 years, respectively, and mean survival rates were 0.98, 0.97, 0.97, and 0.99, respectively. From 1988 through 1997, 1998 through 2002, and 2003 through 2007, neonatal mortality rates were 4 of 16, 5 of 20, and 2 of 14 neonates, respectively. During these 3 study periods, mean annual survival rates for calves ≤ 3 years old (excluding neonates that died at ≤ 30 days old) were 0.97, 0.92, and 0.99, respectively.

Conclusions and Clinical Relevance—Although there were limitations to the measurement of some health indicators, use of multiple methods indicated that the health of dolphins in the MMP population was comparable to, if not better than, that published for other dolphin populations. The MMP population of dolphins may provide useful reference values of health indicators for use in assessment of other managed dolphin populations. (J Am Vet Med Assoc 2011;238:356–360)

The MMP has housed and cared for marine mammals for over 45 years, including a population of bottlenose dolphins (Tursiops truncatus). A number of recent clinical research studies have involved the use of dolphins in the MMP population to determine baselines for healthy, normal dolphins, including hematologic reference ranges,1 estimated glomerular filtration rates,2 and circulating IgG concentrations.3 This population has also been used for case-control studies related to nephro lithiasis,4 chronic, phasic high aminotransferases activity,5 and treatments for hemochromatosis.6 Because of the growing use of this population as a baseline for health and disease in bottlenose dolphins, a need was identified to characterize the overall health of dolphins in the MMP population.

Several methods have been used to measure the health of marine mammal populations, including population age structures,7,8 median survival ages,9 annual survival rates,10 mortality rates,11,12 and calf mortality rates.13–15 The purpose of the study reported here was to evaluate these health indicators for bottlenose dolphins in the MMP population by use of data acquired from 1988 through 2007.

Materials and Methods

Age determination—Dolphins have not been collected from the wild for the MMP since 1989, and actual birth dates were used for all dolphins that were captive born. A total of 167 dolphins were included in population age structure analyses, with the exception of neonates that died within 30 days after birth, which were excluded. Of dolphins that originated from the wild during the study period, birth dates were estimated at the time of capture by use of body length-to-weight relationships16 or tooth aging by means of stained sections,17,18 along with general physical features associated with young dolphins between 5 and 10 years old. Body weight-to-length relationships used at time of collection were consistent with those later published16 and were in agreement with ages determined by midmandible tooth extraction in the 1970s.19,20

Study population—A dolphin was considered part of the population for any given year from 1988 through 2007 that was between its birth date (if born in the MMP) or acquisition date and the date of death or transfer to another institution. Descriptive analyses for the study population included sex distribution, origin

From the National Marine Mammal Foundation, 2240 Shelter Island Dr, San Diego, CA 92106 (Venn-Watson, Ridgway); and the US Navy Marine Mammal Program, 53560 Hull St, San Diego, CA 92106 (Jensen). The authors thank Dr. Cynthia Smith, Dr. Mark Xitco, and Mike Rothe for technical assistance. Address correspondence to Dr. Venn-Watson (stephanie@epitracker.com).
of the dolphin (born in the MMP, born at other institution, or wild caught), custody date ranges, and transfer of dolphins to other institutions (eg, breeding loans).

Population age structure—Ages of dolphins in the population for each year were determined by subtracting the birth date from the last date (ie, December 31) of each study year or the death or transfer date of a dolphin. Mean ± SD and median (range) ages of dolphins were calculated for the dolphin population of each year. Annual percentages of dolphins in the following age groups were calculated every 5 years (ie, for 1988, 1993, 1998, 2003, and 2007): > 30 days to 2 years old, > 2 to 5 years old, > 5 to 10 years old, > 10 to 20 years old, > 20 to 30 years old, and > 40 years old.

Neonatal deaths and calf survival rates—Calves were defined as dolphins that were < 3 years old. The total number of dolphins born alive from 1988 through 2007 was determined; stillborn dolphins were not included in the study. Neonates were defined as dolphins that were ≤ 30 days old. Three groups were created to compare the 10 years before initiation of the formal breeding program in 1998 (1988 to 1997), the first 5 years of the breeding program (1998 to 2002), and the second 5 years of the breeding program (2003 through 2007). Neonatal mortality rates for year groups were calculated as the number of neonatal deaths divided by the number of dolphins born.

Calf survival rates were limited to calves that lived > 30 days. Survival rates were calculated by use of the following equation for calves that were < 3 years old during any given study year:

Calf survival rate = actual live calf days/expected live calf days

in which actual live calf days = (December 31 or death date) – (January 1 or birth date) and expected live calf days = (December 31) – (January 1 or birth date). Calf survival rates were determined for the following year groups: 1988 to 1997, 1998 to 2002, and 2003 to 2007.

Median survival age—Median survival age and survival rates were determined for 1988 to 2007 and during 5-year periods (1988 to 1992, 1993 to 1997, 1998 to 2002, and 2003 to 2007). Median survival ages were calculated by determining the ages of dolphins at death (date of death – estimated or actual birth date) and calculating the 50th percentile within each study period.

Mortality rates—Mortality rates for dolphins were determined for 1988 to 1992, 1993 to 1997, 1998 to 2002, and 2003 to 2007 by calculating total number of deaths divided by total animal years. Dolphins that died within 30 days after birth were not included in the determination of mortality rates. Age-specific mortality rates were calculated by use of 3 age groups (> 3 to 10 years old, > 10 to 30 years old, and > 30 years old). Wide age group ranges were selected to maximize the number of dolphins per age group and to account for dolphins with estimated ages, in which estimations were expected to be accurate for these 3 groups.

Survival rates—By use of a non–age-dependent method recommended by DeMaster and Drvenak, survival rates were based on the number of live days in custody per study period. Specifically, the following equation was used to calculate survival rates of dolphins for 1988 to 1992, 1993 to 1997, 1998 to 2002, and 2003 to 2007:

Survival rate = total actual live animal days/total expected live animal days

For example, if there were 10 dolphins in a population, we would expect all dolphins to live every day for a given year. Thus, the expected live animal days would be 10 dolphins × 365 days = 3,650 expected live animal days. If a dolphin in this population died midway through the year, then the actual live animal days would be (9 dolphins × 365 days) + (1 dolphin × 182 days) = 3,467 actual live animal days. Therefore, the annual survival rate in this example would be 3,467/3,650 = 0.95. To be included in survival rate analyses, a dolphin had to be alive and in custody during any part of a defined study period. Survival rate analyses did not include stillborn dolphins or dolphins that survived < 30 days after birth.

Statistical analysis—In the analysis of population age structures, linear trends for significant increases or decreases in age groups were assessed by use of linear regression. Significant trends in changes in age groups were defined by values of P < 0.05 and R² > 0.45. A 1-way ANOVA was conducted to compare mean annual mortality rates of dolphins among the 4 study periods of interest (ie, 1988 to 1992, 1993 to 1997, 1998 to 2002, and 2003 to 2007). Values of P < 0.05 were considered significant.

Results

Study population—A total of 167 dolphins were included in the study. The annual mean number of dolphins in the MMP population from 1988 through 2007 was 82 (range, 66 to 104). Sex was reported for 156 dolphins; of these, 69 (44.2%) were female and 87 (55.8%) were male. The range of initial custody or birth dates for dolphins included in the study was September 1962 through August 2007. Of 167 dolphins, 65 (38.9%) had known birth dates (56 dolphins were born in the MMP, and 9 were born at other institutions) and 102 (61.1%) were wild caught with estimated ages; estimated ages were based on tooth aging (19/167; 11.4%) or on body length-to-weight relationships and other physiologic traits (83/167; 49.7%). A total of 25 of the 167 (15%) dolphins were transferred to other institutions (median age at transfer, 15.3 years; range of ages at transfer, 6 to 22.4 years) during the study; 22 of these 25 (88%) dolphins were breeding females that were transferred from 1994 through 2000 because of an anticipated downsizing of the MMP, which was subsequently reversed during 2001.

Population age structure—Annual mean ± SD and median (range) ages of dolphins in the MMP population were recorded (Table 1). Number of dolphins by age group changed over time, including an impact on the age structure between 1998 and 2003 as a re-
Mean annual survival—a to z—From 1988 through 2007, the MST population reflects downsizing in the number of dolphins in the MMP during 1994 through 2000 because of anticipated decreasing need by the US Navy, which was subsequently reversed during 2001.

Mortality rates—Crude mortality rates of dolphins for 1988 to 1992, 1993 to 1997, 1998 to 2002, and 2003 to 2007 were 3.1%, 4.7%, 3.6%, and 2.4%, respectively. No significant (P = 0.37) differences were found in mean annual mortality rates of dolphins among the 4 study periods. Age-specific mortality rates remained stable throughout the study period. During these 4 study periods (ie, 1988 to 1992, 1993 to 1997, 1998 to 2002, and 2003 to 2007), age-specific mortality rates of dolphins that were > 3 to 10 years old were 2.0%, 4.7%, 8.2%, and 1.3%, respectively; mortality rates of dolphins that were > 10 to 30 years old were 4.2%, 3.5%, 3.3%, and 1.9%, respectively; and mortality rates of dolphins that were > 30 years old were 0%, 6.4%, 0%, and 4.5%, respectively.

Annual survival rates—Mean annual survival rates of dolphins for 1988 to 1992, 1993 to 1997, 1998 to 2002, and 2003 to 2007 were 0.98, 0.97, 0.97, and 0.99, respectively.

**Discussion**

We report changes in the age structure of the dolphins in the MMP population that reflect broader representation of all age classes during 2007, compared with that of 1988, 1993, 1998, and 2003. The maximum age of dolphins in the MMP population during the study period was an estimated 50 years, and 8.5% of dolphins in 2007 were aged as > 40 years old. Tooth aging in other populations has determined that dolphins can have a life span up to or exceeding 50 years. Given this information, we consider dolphins in the MMP population that were > 40 years old as geriatric. Along with growing populations of geriatric dolphins, opportunities are beginning to be observed in the MMP to better understand dolphin diseases associated with age, including nephrolithiasis and hemochromatosis.

**Table 1—Annual mean ± SD and median (range) age of bottlenose dolphins (Tursiops truncatus; n = 156) in the managed MMP population from 1988 through 2007.**

<table>
<thead>
<tr>
<th>Year</th>
<th>No. of dolphins</th>
<th>Mean ± SD</th>
<th>Median (range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1988</td>
<td>102</td>
<td>11.6 ± 7.4</td>
<td>9.6 (0.2–31.6)</td>
</tr>
<tr>
<td>1989</td>
<td>107</td>
<td>12.3 ± 7.3</td>
<td>9.6 (1–32.6)</td>
</tr>
<tr>
<td>1990</td>
<td>104</td>
<td>12.3 ± 7.3</td>
<td>10.6 (3–33.6)</td>
</tr>
<tr>
<td>1991</td>
<td>106</td>
<td>14.0 ± 7.5</td>
<td>11.6 (0–34.6)</td>
</tr>
<tr>
<td>1992</td>
<td>106</td>
<td>14.3 ± 7.7</td>
<td>12.6 (0–35.6)</td>
</tr>
<tr>
<td>1993</td>
<td>105</td>
<td>14.8 ± 7.9</td>
<td>13.6 (0–36.6)</td>
</tr>
<tr>
<td>1994</td>
<td>101</td>
<td>15.7 ± 8.1</td>
<td>14.6 (0.3–37.6)</td>
</tr>
<tr>
<td>1995*</td>
<td>91</td>
<td>17.0 ± 8.4</td>
<td>15.8 (0.3–38.6)</td>
</tr>
<tr>
<td>1996*</td>
<td>86</td>
<td>17.9 ± 8.3</td>
<td>16.6 (1.3–39.6)</td>
</tr>
<tr>
<td>1997*</td>
<td>77</td>
<td>18.6 ± 8.3</td>
<td>17.6 (2.3–40.6)</td>
</tr>
<tr>
<td>1998*</td>
<td>78</td>
<td>18.3 ± 9.0</td>
<td>18.2 (0.1–41.6)</td>
</tr>
<tr>
<td>1999*</td>
<td>79</td>
<td>19.1 ± 9.2</td>
<td>18.8 (0.4–42.6)</td>
</tr>
<tr>
<td>2000*</td>
<td>77</td>
<td>19.5 ± 9.6</td>
<td>19.6 (0.5–43.6)</td>
</tr>
<tr>
<td>2001*</td>
<td>72</td>
<td>19.6 ± 11.0</td>
<td>20.6 (0.2–44.6)</td>
</tr>
<tr>
<td>2002</td>
<td>75</td>
<td>19.2 ± 11.9</td>
<td>21.6 (0.1–45.6)</td>
</tr>
<tr>
<td>2003</td>
<td>73</td>
<td>20.7 ± 11.7</td>
<td>22.6 (1.1–46.6)</td>
</tr>
<tr>
<td>2004</td>
<td>74</td>
<td>21.1 ± 12.1</td>
<td>23.1 (0.4–47.6)</td>
</tr>
<tr>
<td>2005</td>
<td>79</td>
<td>20.0 ± 12.5</td>
<td>22.2 (0.0–48.6)</td>
</tr>
<tr>
<td>2006</td>
<td>77</td>
<td>20.8 ± 12.6</td>
<td>22.6 (0.7–48.6)</td>
</tr>
<tr>
<td>2007</td>
<td>82</td>
<td>20.4 ± 13.3</td>
<td>24.6 (0.4–50.6)</td>
</tr>
</tbody>
</table>

*Indicates years affected by active downsizing of the number of dolphins in the MMP (22 dolphins were transferred from 1994 through 2000) because of anticipated decreasing need by the US Navy, which was subsequently reversed during 2001.
Although population age structures are commonly used to assess the health of natural animal populations or to determine the minimum number of animals needed to sustain an endangered population,\textsuperscript{31,32} they are less useful indicators of health in populations that have controlled breeding programs, animal transfers, and animals that were wild caught. Further, the high percentage of dolphins in the MMP population with estimated ages allows only analyses with broad age categories. Thus, age structures of dolphins in the MMP population are useful in documenting changing health needs for changing age distributions of dolphins and for comparison of maximum ages reached by dolphins at the MMP with those reached by wild dolphin populations. Annual age structures of the dolphins in the MMP population, however, are limited in their ability to assess health related to middle age dolphins over time and are not considered a primary measurement of population health.

Since the implementation of a formal dolphin breeding program in 1998, the MMP doubled the number of neonates (n = 34), compared with the number of neonates 10 years before the breeding program was initiated (16). Although the neonatal mortality rate for 1988 to 1997 and for 1998 to 2002 was 4 of 16 and 5 of 20 neonates, respectively, the rate decreased to 2 of 14 neonates for 2003 to 2007. Neonatal deaths usually occurred within 2 days after birth, and most of these deaths were attributed to bacterial infections secondary to failure of passive transfer. The decrease in neonatal deaths from 2003 through 2007 was attributed to a neonatal health promotion program that included handling neonates in the water within hours to days after birth for physical examinations and blood sample collection, detection of subclinical infections, and, when appropriate, provision of colostrum and antimicrobial treatment. Neonates that did not nurse within 12 hours after birth were provided colostrum collected from the dam, and if nursing continued to be unsuccessful with the dam, surrogate dams were provided for milk.

Mean annual survival rates for calves < 3 years old (excluding calves that died at < 30 days old) for 1993 to 1997, 1998 to 2002, and 2003 to 2007 were 0.97, 0.92, and 0.99, respectively. Previously published annual survival rates for neonatal calves born in captivity during 1983 and from 1988 through 1992 were 0.61 and 0.67, respectively, which was less than annual survival rates in older (noncall) dolphins (0.95).\textsuperscript{10,22} In the MMP from 2003 through 2007, the mean annual survival rates for calves that lived at least 30 days and older (noncall) dolphins were the same (0.99). Given known birth dates and health outcomes of captive-born dolphins in the MMP, both the neonatal mortality and calf survival rates serve as appropriate means for characterizing health of young dolphin populations.

From 2003 through 2007, the median survival age in our population was 26.1 years. A previously reported median survival age of oceanarium dolphins was 17 years.\textsuperscript{33} Although the MMP results appear encouraging, interpretation of this metric is greatly limited because of its dependency on the population age structure, which is influenced by controlled breeding and animal transfers to other institutions, and accurate ages, which is limited to estimations based on tooth aging and body length-to-weight relationships among wild-caught animals. As such, median survival age is a less valid measurement of health over time of the dolphins in the MMP population and is not comparable with that of other dolphin populations.

Crude mortality rates among dolphins in the MMP population were maintained below 3% throughout the study period, with a rate of 2.4% from 2003 through 2007. A previously reported mortality rate of oceanarium dolphins was 7%.\textsuperscript{31,34} Despite an increase in the percentage of older dolphins over time (including dolphins that were > 40 years old), annual mortality rates remained low and did not change significantly over time for dolphins in the MMP population. This finding is consistent with improved management and treatment of chronic disease in aging dolphins, including iron overload and urate nephrolithiasis.\textsuperscript{35-37} Age-specific mortality rates also remained between 0% and 5%, with the exception of dolphins that were > 30 years old from 1993 through 1997 (6.4%) and dolphins that were between 10 and 30 years old from 1998 through 2002 (8.2%). A clear reason for slightly higher mortality rates among older dolphins from 1993 through 1997 was not identified. What appeared to be a cluster of inflammatory disease, including fungal infections, occurred among dolphins from 1999 through 2000, causing an increased mortality rate for middle-aged dolphins during this period.

Use of crude mortality rates helped to assess consistency of health of dolphins in the MMP, even with an increase in the number of older dolphins. Although age-specific mortality rates may have been limited because of the high number of dolphins with estimated ages and use of wide age ranges (> 3 to 10 years old, 10 to 30 years old, and > 30 years old), the wide ranges decreased the need for extreme accuracy in age estimation, and this method successfully identified changes in mortality rates by age and year. Given these assets, both crude and age-specific mortality rates were useful measures of the health of dolphins in the MMP population.

Because of the limited comparability of several health indicators across populations and the limitations of age-dependent health indicators, DeMaster and Drevenak\textsuperscript{10} recommended the use of survival rates on the basis of live animal days in custody to compare the health of different marine mammal populations. In their study, they reported a mean dolphin population survival rate of 0.93 with a recommended target survival rate range of 0.90 to 0.95; rates above this range were indicative of superior husbandry practices. To maintain a stable wild dolphin population, Reilly and Barlow\textsuperscript{23} recommended an estimated survival rate of 0.92 to 0.95. Annual survival rate reported in Sarasota, Fla, for the wild bottlenose dolphin population was 0.96,\textsuperscript{23,24} and the annual survival rate for bottlenose dolphins in the Indian-Banana River area was between 0.91 and 0.93.\textsuperscript{23}

In our study, the mean annual survival rates among dolphins in the MMP population that lived > 30 days for 1988 to 1992, 1993 to 1997, 1998 to 2002, and 2003 to 2007 were 0.98, 0.97, 0.97, and 0.99, respectively. DeMaster and Drevenak\textsuperscript{10} posed the assumption that institutions with greater numbers of calves were
expected to have lower survival rates. Although the number of live calf births doubled in the MMP from 1998 through 2007, compared with that from 1988 through 1997, we did not find a decrease in survival rates. Compared with all other health indicators evaluated in our study, annual survival rates appeared to be the best non-age-dependent means of assessing health over time for dolphins in the MMP population. Use of survival rates remains limited because of the occasional transfer of dolphins of various ages in and out of this population. Most of the dolphins that were transferred during the study period, however, were healthy, reproducing females and not old dolphins with chronic illness; thus, it is not expected that animal transfers resulted in falsely high survival rates.

In conclusion, health indicators that were the most useful for dolphins in the MMP population over time were the neonatal mortality rates, calf mean annual survival rates, and adult (noncalf) mean annual survival rates. On the basis of these health indicators, the health of dolphins in the MMP population appears to be comparable to, if not better than, that of other dolphin populations. The MMP population of dolphins may provide useful reference values of health indicators for other managed dolphin populations.

References

23. Reilly SB, Barlow JP. Rates of increase in dolphin population size. Fish Bull (Wash DC) 1986;84:527–533.