Evaluation of annual survival and mortality rates and longevity of bottlenose dolphins (*Tursiops truncatus*) at the United States Navy Marine Mammal Program from 2004 through 2013

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Objective—To evaluate annual survival and mortality rates and the longevity of a managed population of bottlenose dolphins (*Tursiops truncatus*).

Design—Retrospective cohort study.

Animals—103 bottlenose dolphins at the US Navy Marine Mammal Program (MMP).

Procedures—Population age structures, annual survival and crude mortality rates, and median age at death for dolphins > 30 days old were determined from 2004 through 2013.

Results—During 2004 through 2013, the annual survival rates for MMP dolphins ranged from 0.98 to 1.0, and the annual crude mortality rates ranged from 0% to 5%, with a mean of 2.7%. The median age at death was 30.1 years from 2004 through 2008 and increased to 32 years from 2009 through 2013. The maximum age for a dolphin in the study was 52 years.

Conclusions and Clinical Relevance—Results indicated that the annual mortality rates were low and survival rates were high for dolphins in the MMP from 2004 through 2013 and that the median age at death for MMP dolphins during that time was over 10 years greater than that reported in free-ranging dolphins. These findings were likely attributable to the continually improving care and husbandry of managed dolphin populations. (*J Am Vet Med Assoc* 2015;246:893–898)

The US Navy MMP has housed and cared for bottlenose dolphins (*Tursiops truncatus*) for over 50 years. Because of the clinical and biological research conducted over the past half century, knowledge of dolphin physiology, clinical medicine, and behavior at the MMP has expanded greatly.[1–7] Specifically, clinical research has advanced dolphin medicine in areas such as diagnostic imaging, infectious and metabolic disease discovery and health assessments, and the establishment of reference ranges for blood-based indicators of health and immune status.[8–16] This research has improved the scientific community's general understanding of dolphin physiology and is being applied to the routine care and health assessments of dolphins.

Abbreviation

MMP Marine Mammal Program

Some of the greatest risks to the health of the global human population are infectious diseases, malnutrition, and lack of access to medical care; when those challenges are minimized, the health of human populations improves.[17] Access to advanced medical care and good husbandry practices is expected to improve the health and welfare of dolphin populations in an analogous manner. For populations that are sufficiently large to enable reasonable interpretations over time, general health indicators include population age structure, median age at death, and annual survival and mortality rates.[18–21] In a previous survey[22] of health population data for dolphins at the MMP, health indicators were assessed in 5-year intervals between 1988 and 2007. Results of that survey[22] indicate that during that period, the number of young (neonates) and old (> 40 years) dolphins increased, the median age at death increased from 14 to 26 years, the 5-year crude mortality rate ranged from 2.4% to 4.7%, and the mean annual survival rates ranged from 0.97 to 0.99. The purpose of the study reported here was to assess population health indicators for the dolphins at the MMP from 2004 through 2013 and compare them with the population health indicators for dolphins at the

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MMP from 1994 through 2003 and free-ranging bottlenose dolphins. Additionally, aspects of the medical care, husbandry, and knowledge of dolphins gained during the past decade that may have contributed to improved dolphin health were reviewed.

Materials and Methods

Animals—All 103 bottlenose dolphins in the care of the MMP during the period from 2004 through 2013 were included in the study, regardless of their geographic location. A dolphin was considered to be present in the population during a given year if the year fell between or included its birthdate or date of arrival into the program and the date it died or was removed from the program (ie, gone date). Dolphins in the MMP are fed restaurant-quality, frozen-thawed fish, undergo routine physical examinations, are administered anthelminthic treatments, are housed in netted enclosures in the ocean, and routinely work in the open ocean.

Data collection and analysis—Data extracted from the MMP database for each dolphin included its unique identification, sex, birthdate, arrival date (date the dolphin entered the MMP if different from the birthdate), gone date (date the dolphin died or was removed from the MMP), gone year (year that the dolphin was removed from the MMP), disposition for each year (alive, dead, or transferred), and gone age (eg, gone age = gone date – birthdate). Of the 103 dolphins in the study, 56 (54.4%) had known birthdates, and 47 (45.6%) were captured from a free-ranging population with age estimated on the basis of teeth and other methods as described.[22] It is important to note that dolphins at the MMP have not been acquired from free-ranging populations for over 25 years. For each dolphin each year, the number of days survived was equal to the gone date minus January 1 if the dolphin died during the year, the birthdate minus January 1 of the next year if the dolphin was born that year, or 365 if it survived the entire year. Its age in years for each year was calculated as (June 15 – birthdate)/365 if it survived the entire year or (gone date – birthdate)/365 if it died or was removed from the population that year. Descriptive data were created, and outcomes of interest were analyzed with statistical software.[a]

Population age structure—The median and maximum ages for all dolphins at the MMP were calculated for each year. The population age structure consisted of the percentage of dolphins in each of 6 categories (0 to 5 years, > 5 to 10 years, > 10 to 20 years, > 20 to 30 years, > 30 to 40 years, and > 40 years) and was calculated for 2004, 2007, 2010, and 2013.

Median age at death and population age—Age at death in years was calculated as (gone date – birthdate)/365 for dolphins that died. For dolphins ≥ 30 days old, the median (50th percentile) age at death was determined for those that died from 2004 through 2008 and from 2009

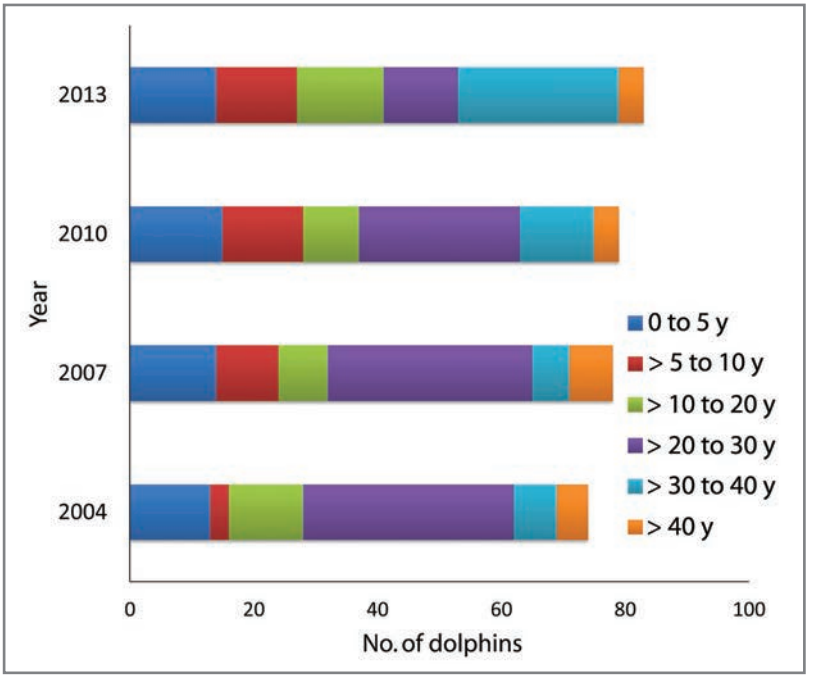

Figure 1—Population age structure for bottlenose dolphins (*Tursiops truncatus*) at the US Navy MMP from 2004 through 2013.

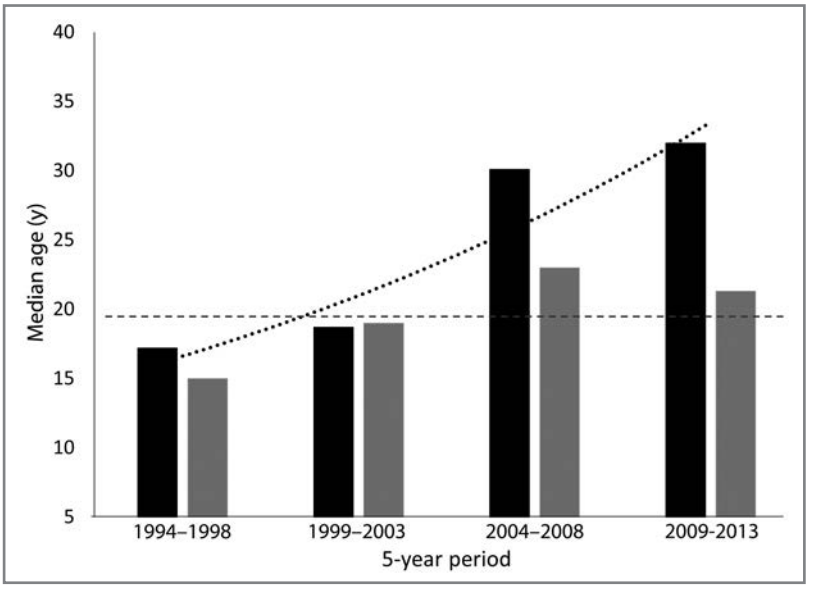

Figure 2—Median age at death (black bars) and median population age (gray bars) for bottlenose dolphins ≥ 30 days old at the MMP from 1994 through 2013. The dotted line represents the increase in the median age at death from 1994 through 2013. The horizontal dashed line represents the median age at death for free-ranging dolphins in Sarasota Bay, Fla, reported by Wells et al.[24] Data for the MMP dolphins from 1994 through 2003 were obtained from Venn-Watson et al.[22]

through 2013 and compared with the median age of death for dolphins at the MMP from 1994 through 1998 and from 1999 through 2003 that was reported in another study.[22] The median population age was also determined and compared among those periods to assess whether changes in the median age at death was a function of median population age.

Annual birthrate and crude mortality rate—The annual birthrates (ie, the number of dolphins born during a year/the total number of dolphins in the population that year) were calculated and compared with the annual crude mortality rates (ie, the number of dolphins that died during a year/the total number of dolphins in the population that year). Because it is difficult to determine the mortality rate for dolphins < 30 days old in free-ranging populations, dolphins < 30 days old that died at the MMP were excluded from the calculation of the annual crude mortality rates to ensure consistency and enable comparisons with results of previous studies[23–25] of free-ranging dolphins. Age-specific mortality rates were not calculated because of the low number of deaths within the MMP dolphin population.

Annual survival rate—Survival rate was calculated on the basis of the non–age dependent methodology described by DeMaster and Drevnak[23] and represented the actual versus expected number of live dolphin-days per year. For each year from 2004 through 2013, the annual survival rate was equal to the number of actual live dolphin-days divided by the number of expected live dolphin-days. This model assumes continuous survival for all dolphins ≥ 30 days old during each year. For example, if there were 10 dolphins in a population, we would expect all 10 to live every day for a given year, and the expected live dolphin-days would be 3,650 (10 dolphins × 365 d/y). If one of the dolphins died 182 days into the year, then the actual live dolphin-days would be 3,467 ([9 dolphins × 365 days] + [1 dolphin × 182 days]), and the annual survival rate would be 0.95 (3,467/3,650). All dolphins ≥ 30 days old that were part of the MMP during any part of a given year were included in the survival rate calculation for that year.

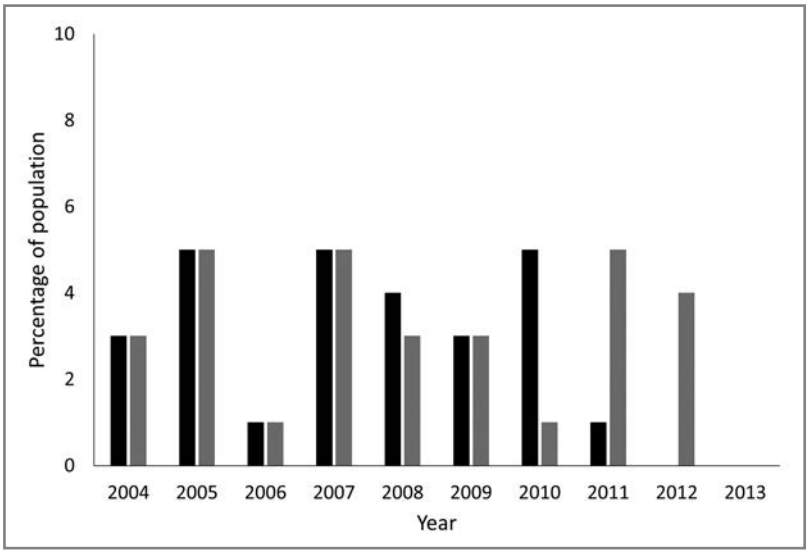

Figure 3—Annual birthrates (gray bars) and crude mortality rates (black bars) for bottlenose dolphins ≥ 30 days old at the MMP from 2004 through 2013.

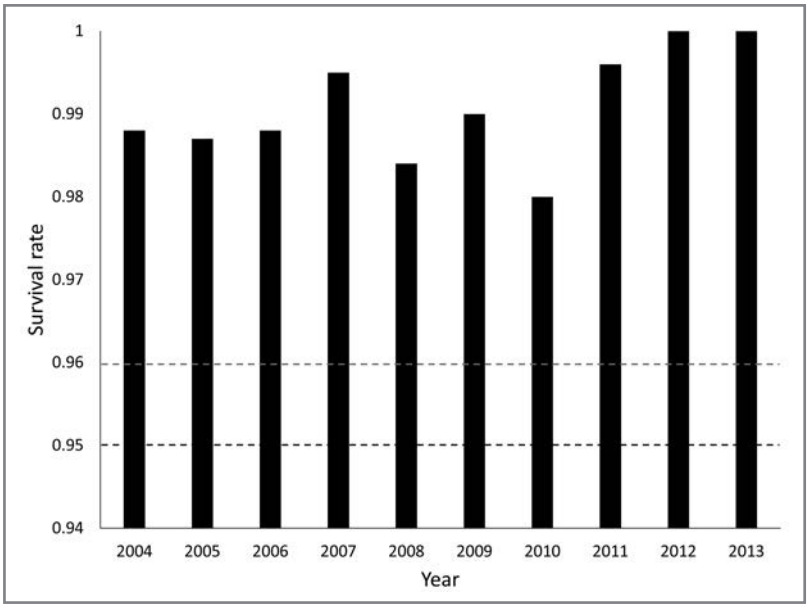

Figure 4—Annual survival rates for bottlenose dolphins ≥ 30 days old at the MMP from 2004 through 2013. Survival rate was calculated on the basis of the non–age dependent methodology described by DeMaster and Drevnak[23] and was equal to the number of actual live dolphin-days divided by the number of expected live dolphin-days. The dashed black line represents the survival rate necessary to maintain a stable free-ranging bottlenose dolphin population reported by Reilly and Barlow.[30] The dashed gray line represents the estimated survival rate for free-ranging dolphins in Sarasota Bay, Fla, reported by Wells and Scott.[27]

Results

Dolphins—One hundred three dolphins were cared for at the MMP during the period from 2004 through 2013, of which 40 (38.8%) were female and 63 (61.2%) were male. The mean annual number of dolphins in the MMP was 79 (range, 74 to 83). Only 3 (2.9%) dolphins were transferred from the MMP to other institutions during the study period, and all 3 were transferred during 2007. The initial arrival or birthdates for dolphins included in the study ranged from June 1968 to May 2013. The maximum age for a study dolphin was 52 years.

Population age structure—The population age structure changed during the study period so that the percentages of dolphins within each age group were more evenly distributed (**Figure 1**). During 2013, 30 of 83 (36%) MMP dolphins were > 30 years old, and 4 (5%) of those were > 40 years old.

Median age at death—Seventeen dolphins ≥ 30 days old died during the study period. The median age at death was 30.1 years during the period from 2004 through 2008 and 32 years during the period from 2009 through 2013, compared with 17.2 years during the period from 1994 through 1998 and 18.7 years during the period from 1999 through 2003 (**Figure 2**).[22]

Annual birthrates and crude mortality rates—Both the annual birthrate and crude mortality rate for dolphins in the MMP ranged from 0% to 5% for the period from 2004 through 2013 (**Figure 3**). The mean annual mortality rate was 2.7%, and the annual birthrate was similar or equal to the annual crude mortality rate for most of the years during the study period.

Annual survival rates—The annual survival rates ranged from 0.98 to 1.0 during the study period (**Figure 4**). Given these high survival rates, further analyses by age category were not conducted.

Discussion

Results of the present study indicated that the median age at death (30 to 32 years) for dolphins at the MMP during the 10-year period from 2004 through 2013 was almost twice the median age at death (17.2 to 18.7 years)[22] for dolphins at the MMP during the previous 10-year period from 1994 through 2003. This increase in the median age at death was accompanied by a stable number of dolphins in the population and a moderate increase in the median population age, which suggested that the increased longevity of the dolphins at the MMP was not solely caused by a change in the age structure of the population (eg, a lack of young dolphins). The mean age at death for a closely monitored population of healthy free-ranging dolphins in Sarasota Bay, Fla, is 19.9 years.[24] Results of another study[25] of free-ranging dolphins in the Indian River Lagoon of Florida indicate that the mortality rate increases exponentially for dolphins > 15 years old and few dolphins survive > 30 to 35 years. Free-ranging dolphins from Northeast Florida are estimated to live a mean of 25 years.[26] In 2013, 30 of 83 (36%) dolphins in the MMP were > 30 years old, and the oldest dolphin in the population was 52 years old, which indicated that a substantial proportion of the dolphins at the MMP were surviving longer than the expected mean life span reported for free-ranging dolphin populations.[24–26]

In the present study, the overall mean annual crude mortality rate was 2.7% and the mean annual survival rate was 0.99 for the dolphins at the MMP. These rates are consistent with the mean 5-year crude mortality (2.4% to 4.7%) and survival (0.97 to 0.99) rates reported for the dolphins at the MMP from 1988 to 2007,[22] which suggested that MMP dolphins have a high likelihood of survival regardless of whether they were acquired from a free-ranging population prior to 1989 or were born at the MMP. The annual mortality rates for dolphins in Sarasota Bay range from 0% to 8%, and the survival rate is 0.96.[27] Free-ranging dolphins in the Indian River Lagoon, a population with apparent declining health attributed to exposure to coastal contaminants, have a mean annual mortality rate of 9.8%.[25] It is estimated that survival rates ranging from 0.92 to 0.95 are necessary to maintain a stable free-ranging dolphin population.[28–30] Collectively, the present study's findings suggested that the dolphins at the MMP have higher annual survival rates and lower annual crude mortality rates than those of free-ranging dolphins.

Comparisons of the findings for the managed dolphins of the present study with those for free-ranging dolphins are conservative because they included only dolphins ≥ 30 days old. The survival rate and median age at death for free-ranging dolphins would be further decreased if the calculations included dolphin calves < 30 days old, which are difficult to account for in the wild. For example, the estimated minimal annual mortality rate is 18.9% and the maximum annual survival rate is 0.80 for dolphins < 1 year old in Sarasota Bay,[27] and the mortality rate is 44% for free-ranging dolphins ≤ 3 years old in Shark Bay, Australia.[31]

The foundation for the present study was the belief that the continuous improvement in clinical care and husbandry for dolphins at the MMP would result in improvements in population health indicators during the 10-year period from 2004 through 2013, compared with the same indicators during the previous 10-year period. Long-term best practices related to husbandry, housing, training, nutrition, and preventive medicine likely contributed to the continued low mortality rates and high survival rates for dolphins at the MMP. During the past 10 years, several key programs and practices have been built and implemented to further improve the care of managed dolphins and may have contributed to the increased longevity of those animals.

Similar to humans, advanced age has been identified as a risk factor for bacterial pneumonia in dolphins.[32–34] Unlike humans, however, dolphins can mask overt evidence of infections until disease reaches an advanced stage, an ability that is believed to help them evade predators.[35] Until the past 10 years, traditional diagnostics were frequently limited to aerobic and anaerobic bacterial and fungal cultures of swab specimens obtained from the blowholes of dolphins with advanced disease. Currently available diagnostic imaging procedures, such as ultrasonography, radiography, CT, and the use of CT- or ultrasound-guided fine needle aspiration and biopsy techniques to obtain specimens of diseased tissues, along with the development and use of broth cultures and PCR assays for the detection of various pathogens, have improved the ability to identify and confirm infections in the early stages of disease, characterize the severity of the disease, and monitor the response to treatment.[14,35–37] These advanced methods for disease detection and the effective use of hydration and targeted, time-limited IV administration of antimicrobials for the treatment of infectious disease (a cause of death in wild and managed dolphin populations) have likely contributed to the longevity of managed dolphins.[14,35–37]

Dolphins at the MMP are trained to be transported, which allows them to be readily transported for medical evaluation with minimal stress.[13,38] Use of advanced diagnostic imaging modalities such as CT has helped improve our understanding of dolphin anatomy, identify and characterize disease processes, target interventions,

and monitor response to treatment.[13,14,38] Although well-ventilated anesthesia performed out of the water for a large animal that is typically buoyant can be a challenging task, improvements have occurred in technologies and approaches for successful dolphin anesthesia and surgery, such as hepatic vein catheterization for blood pressure monitoring and medication administration, arterial catheterization for blood pressure monitoring, and the use of laser lithotripsy for treatment of ureteral calculus obstruction.[39,40]

Twice during the study period, a group of 40 to 50 experts in areas such as marine mammal and other animal medicine, human health, advanced diagnostic and medical technologies, geriatric health, immunology, urology, metabolism, infectious disease, and epidemiology convened at the MMP. During the 2.5-day meetings, the group discussed the most pressing clinical research needs for mammals at the MMP, which resulted in a prioritized list of research projects to be implemented over a 5-year period. Clinical advancements that have originated from or progressed as part of these clinical research investment strategies include the diagnosis and treatment of iron overload, development of PCR assays and risk assessments for known marine mammal–associated viruses and bacteria, identification and use of adipose-derived regenerative (ie, stem) cells, development of dolphin-specific immune assays, discovery of dolphin-specific commensal-based probiotics, standardization and use of advanced imaging for disease detection, detection of and identification of risk factors associated with subclinical metabolic syndrome, identification of risk factors associated with ammonium urate nephrolithiasis, use of breath analysis for clinical assessments, and identification of targeted syndromes associated with advanced age.[7,9,10,12–14,16,41–45] These clinical research successes have been, in part, the result of focus on the highest-priority clinical needs, the ability to train dolphins to perform certain behaviors that facilitate examination, access to clinical and longitudinal dolphin health data and archived biological specimens, collaborations with leading national experts, and adequate funding. Future areas of interest include environmental research that may benefit the health of both managed and free-ranging dolphins and elucidation of the changing dietary, social, and environmental needs of dolphins as they age.

The findings of the present study indicated that the longevity of dolphins at the MMP has improved during the past 10 years, compared with that during the previous decade, and that dolphins in the MMP live a mean of approximately 10 years longer than do their free-ranging counterparts. Furthermore, the mortality rates continue to be low and the survival rates remain high for dolphins at the MMP. It is perhaps not surprising that dolphins at the MMP have better overall health, compared with free-ranging dolphins, because they are protected from natural predators, human-based threats (eg, fishing bycatch), calf abandonment, and foodborne parasitic diseases. Similar to improved human population health because of improved access to or advancements in medical care, the improved longevity for dolphins at the MMP is likely the result of multiple factors associated with marine mammal medicine and husbandry, including targeted detection of and response to infectious diseases; advancements in diagnostic imaging, anesthesia, and surgery; incorporation of a wide variety of specialists into marine mammal practice; a fairly small doctor-to-patient ratio; development and implementation of targeted and prioritized 5-year clinical research investment strategies; and application of a one health approach that involves active engagement by medical experts in human health.

a. SAS, version 9, SAS Institute Inc, Cary, NC.

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