JZAR www.jzar.org JOURNAL OF ZOO AND AQUARIUM RESEARCH

JZAR Evidence-based practice

OPEN ACCESS

Evidence-based practice

Age and growth of the zebra shark *Stegostoma tigrinum* (Forster 1781), at Loro Parque Aquarium

Héctor P. Toledo, Pedro M. Callejas, Ana H. Alfaro, Henrique R. Guimeráns and Ester G. Alonso

Loro Parque Aquarium, Canary Islands, Spain.

Correspondence: Héctor P. Toledo, email; hectortp92@gmail.com

Keywords: age, aquarium, growth, length, *Stegostoma tigrinum*, weight

Article history:
Received: 12 Feb 2022
Accepted: 25 Jul 2022
Published online: 31 Jul 2022

Abstract

Breeding programmes have been developed at the Loro Parque Aquarium for the past eight years focusing mainly on zebra sharks *Stegostoma tigrinum*. These programmes provide the possibility to study the growth of specimens and the relation between age, length and weight. Data obtained from a total of 288 biometric measurements from 24 (12:12:0) specimens were analysed, of which 18 (9:9:0) were born at Loro Parque. At the time of birth (t_0) the average total length (TL) of the new-borns was 26.5 cm and the average total weight (TW) was 71.94 g. The von Bertalanffy growth function (vBGF) obtained, where $y=186.78\times[1-e^{-0.56\times(x-0.27)}]$, shows accelerated growth (k=0.56) within the first 3.5 years (1200 days) of life. No significant difference was found between growth of males and females. To study the length-weight relationship, a regression analysis was performed with $TW=2.16\times10{-}4\times TL^{3.54}$ presenting a positive allometric relationship and $R^2=0.9857$, which demonstrates strong correlation between the variables.

Background

The zebra shark *Stegostoma tigrinum* can be found in tropical and subtropical coastal areas at 0–62 m depth (Compagno 1984; Ebert et al. 2013), and genetic studies have revealed the existence of two different subpopulations: Indian-Southeast Asia and Eastern Indonesian-Oceania (Dudgeon et al. 2009).

S. tigrinum is a benthic shark with a cylindrical body and a maximum known length of 246 cm (Dudgeon et al. 2008). Males reach sexual maturity at 165 cm in length and females at around 170 cm in length (Ebert et al. 2013). Their life expectancy is estimated at 25–30 years (Compagno 2001). *S. tigrinum* is an oviparous species that lays rectangular-shaped eggs with a longitudinal tuft and a size of approximately 17×8×5 cm. Under human care, annual egg-laying cycles last up to five months, and between 18 and 54 eggs are laid each year (Dudgeon et al. 2017; Kunze and Simmons 2004; Robinson et al. 2011; Toledo and Alonso 2021). In some isolated cases, *S. tigrinum* has exhibited parthenogenesis (Dudgeon et al. 2017; Robinson et al. 2011).

Due to population decline, the International Union for Conservation of Nature (IUCN) rated *S. tigrinum* as Endangered, taking into special consideration the Indian-Southeast Asian population (Dudgeon et al. 2019; White et al. 2006). Despite this, the zebra shark is very common in aquariums worldwide, many of which have contributed to the conservation of this and other elasmobranch species through captive breeding programmes (Uchida et al. 1990). However, specific unified breeding strategies have not been established, leaving mating success to chance as males and females are simply kept together in a tank. Successful captive breeding programmes require the development of optimal conditions and represent a unique opportunity to increase knowledge about the species. The results provided by the data analysis presented below allow a better understanding of the biology of the zebra shark, its life cycle and growth patterns. In addition, this data can be used in conservation programmes and population studies.

Biometric data from sharks is essential to achieve a better understanding of the species. Aquariums allow researchers to obtain data with a certain frequency, which is why they represent an ideal environment for this type of study. The information that aquariums can acquire on the life history of specimens is almost impossible to obtain in such a rigorous way from animals in the wild (Henningsen et al. 2004; Schmid and Murru 1994; Uchida et al. 1990; Van Dykhuizen and Mollet 1992).

Action

In this study, 24 specimens (12 females and 12 males) were studied. Of these 24 specimens, 9 females and 9 males were born at Loro Parque. A total of 288 biometrics were collected from these 24 specimens; at least weight and total length (TL) were obtained from each of them. Biometrics were collected every three months for adults (>120 cm TL), once a month for juveniles (60–120 cm TL), once every fifteen days for new-borns (24–60 cm TL) and once a week during the first month of life.

Simulated seasons—winter and summer—were applied to the tanks where the specimens were maintained. During the summer (May to September), the temperature was kept at 26°C with 16 hours of light, and during the winter (October to April), it was kept at 23°C with 14 hours of light. The transition between seasons (mid-September to mid-October and mid-April to mid-May) was made gradually. The salinity remained constant at 32 g/L all year (Toledo et al. 2022).

Specimens were fed with a wide range of foods, including prawns, cephalopods and mussels (Watson and Janse 2017), “white fish” (Gadidae or similar) and “blue fish” (Clupeidae or similar). Food consumption varied according to life stage. Until the age of four months, new-borns were fed ad libitum. After four months, an intake based on body weight (BW) percentage was established. At this stage, new-borns were fed 4% BW per day, 7 days per week (28% BW/week). Juveniles were fed 4% per day, 5 days per week (20% BW/week) while adults were fed based on 2.5% BW per day, 3 days a week (7.5% BW/week) (Toledo et al. 2022).

Length

Shark measurement techniques are many and varied in their use. In contrast to other studies that used precaudal length (PCL) or fork length (FL), it was decided to use total length (TL). To take measurements, the tail of the specimen was stretched, and the specimen’s total length was obtained. The tip of the measuring tape was placed on the top of the head and laid along the length of the shark’s body, following the curvature of the face and dorsal area, and continuing to the end of the stretched tail.

Some authors advise that TL measurements should be taken from the ventral area of specimens, allowing more exact measurements to be obtained (Mohan et al. 2004). However, the dorsal method described was continued for two reasons. First, it had been used since the first biometrics were collected in the aquarium, so it was continued in that way to remove the need to account for any error introduced by a change in measurement method. Second, various studies consider that the differences between both methods of obtaining TL do not affect more than 5% of the measurements obtained and that this small variation will not affect assessments of whether a specimen is thin or overweight (Mohan et al. 2004).

Weight

The training stretcher was used to obtain the total weight (TW) of the specimens. The size of the training stretcher that was used was chosen in relation to the size of the specimens. The shark entered the stretcher, which was closed at the top and edges using ropes. The stretcher, with the specimen inside, was momentarily removed from the water and hung from a scale. The stretcher’s base is perforated with small holes that allow water to flow out quickly, preventing water from interfering with weighing. The total value obtained minus the weight of the stretcher and the ropes gave the weight of the specimen.

Consequences

Average size at birth

For average size at birth, the data analysed are from biometrics collected from new-born specimens between days 1 and 8 of life. New-born biometrics collected after day 8 were disregarded given the rapid growth shown by offspring in the first days of life. Therefore, the analysis considers measurements taken at birth, time 0 (t_0), as being from the first to the eighth day. The third day was the mean day on which biometrics were collected. Of the 18 specimens born in the facilities, data from 16 were collected within the specified time period.

Biometrics from 16 new-borns (n=16), 9 females and 7 males (9:7:0), were analysed. The TL at t_0 ranged from 24.5 to 28.5 cm (mean=26.5 cm, standard deviation (SD)=1.08 cm). The TW at t_0 ranged from 62 to 100 g (mean=71.94 g, SD=8.64 g). The analysis

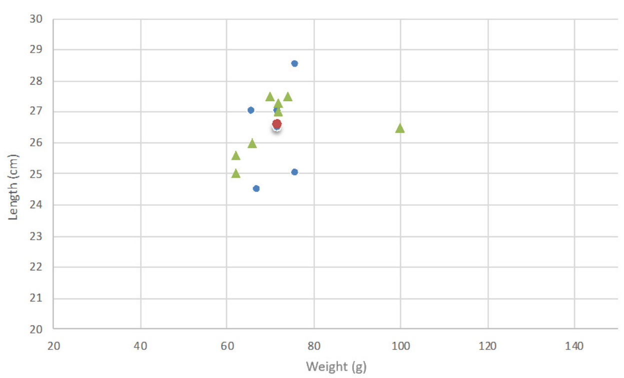

Figure 1. Average size (length and weight) at t = 0 of newborn specimens of zebra shark in the Loro Parque Aquarium. Each marker represents one specimen (n=16). Each green triangle represents a female (n=9). Each blue dot represents a male (n=7). The red dot represents the mean of sizes.

determined that there were no significant differences between females and males at t_0 (Figure 1).

Growth

To study growth, 18 specimens (9 females and 9 males, 9:9:0) were studied, from which 252 pairs of data were obtained (n=252, TL and age). Data from the other six specimens were discarded as their exact age was not known at the time when biometrics were measured. Growth was calculated using the von Bertalanffy growth function (VBGF). The data used ranges from t_0 (day of birth) to the first 3.5 years (1200 days) of life. This age range was selected to maximise the fit of the growth function. Many of the specimens left the facilities as part of the Loro Parque breeding programme.

The VBGF shows accelerated growth in the first life stage (k=0.56), where $y=186.78\times[1-e^{-0.56\times(x-0.27)}]$ (Figure 2). Within the age group studied, no significant difference was found between the growth of males and females.

Length-weight relationship

In the length-weight relationship study, a total of 288 pairs of data (n=288, TW and TL) obtained from the biometrics collected from 24 different specimens (12 females and 12 males) were used. The growth of these specimens over time, added to that of specimens that arrived at the facility in the juvenile phase and grew into adults, made it possible to establish a length-weight relationship that represents the entire growth range.

For the study of the length-weight relationship, a regression analysis was performed where $TW=2.16\times10^{-4}\times TL^{3.54}$, presenting a positive allometric relationship with $R^2=0.9857$ showing strong correlation between the variables (Figure 3). The length-weight relationship for each sex did not show significant differences in the linear regression coefficients of the logarithmically transformed TW-TL data.

Evaluation

The results show a strong positive allometric relationship between length and weight. This relationship makes it possible to study certain factors of physiological condition (Lizama and Ambrosio 2002). However, the possible effect of captivity on the growth of specimens cannot be ignored. Environmental variables, such as water temperature and oxygen dissolution, together with the absence of predator pressure and the provision of food at low energy cost, directly affect the growth of specimens. These factors are related in a specific way to each species and warrant further study (Mohan et al. 2004). In addition, the effect of season cannot be ignored; it is considered to be one of the factors that could most affect the length-weight relationship (Benavides-Morera et al. 2017; Kanaiwa et al. 2011; Oliveira et al. 2012).

Future growth studies can address a number of questions. Some examples include the possibility of establishing a relationship between TL and PCL or TL and FL (Mohan et al. 2004) or researching the association between sexual maturity and clasper features (Kousteni et al. 2010). Data collected by frequently gathering biometrics from specimens and analysing the results creates many opportunities, such as generating a body score condition for *S. tigrinum*. In case of death of the studied specimens, analysis of vertebral annuli could allow assessment of correlation between study methodologies (Compagno 1988).

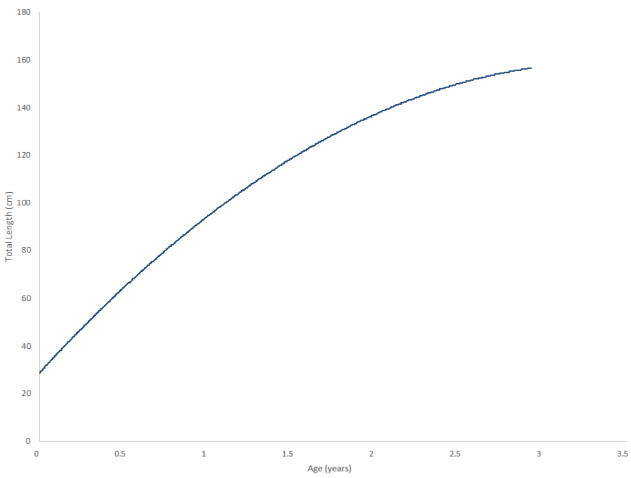

Figure 2. Von Bertalanffy Growth Function modeling total length (cm) versus age (years) for zebra shark (n=252 from 18 specimens) from Loro Parque Aquarium. Length - Age relationship fits from the moment of birth to day 1200.

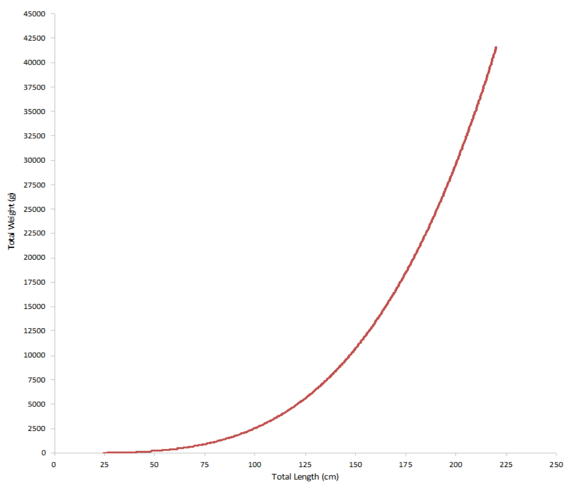

Figure 3. Relationship between length and weight for the zebra shark population in the Loro Parque Aquarium (n=288 from 24 specimens; 12 females and 12 males).

Future perspectives

Breeding programmes provide a unique opportunity to increase knowledge of a species, and this is a key objective for the aquarium at Loro Parque. The continuity of these programmes is crucial and will allow establishment of more reliable and adjusted results.

Following zebra shark husbandry recommendations (Watson and Janse 2017), the data acquired were entered into the integrated animal registration system Species360 (http://www.species360.org) with the aim of generating synergy across entities so the data can be used to enhance zebra shark breeding in other aquariums. Furthermore, the genetic composition of the current population is being studied to assist preservation of genetic variability and health in future generations of zebra sharks. All entities share the common goal of maintaining a self-sufficient and genetically diverse aquarium population that provides a valuable living resource to learn more about this species while reducing pressures on wild populations (Watson and Janse 2017).

Shark populations are essential for marine balance and play a critical role in the health of ecosystems. Therefore, understanding and studying these populations, even in controlled settings, is essential for the future of these ecosystems.

Acknowledgements

Thanks to all of the team for the endless effort and infinite hours dedicated to the animals and the breeding programme. Without the involvement of Loro Parque and Loro Parque Fundación the development of this study would not have been possible. Loro Parque Fundación supports animal welfare and biodiversity conservation through research and education. Loro Parque, as a modern zoo, dedicates a great amount of effort and resources to breeding programmes in order to gain knowledge and improve protection.

References

Benavides-Morera R., Brenes-Rodríguez C.L., Márquez-Artavia A. (2017) Sex ratio, length-weight relationship and geographic-bathymetric distribution of *Squalus cubensis* (Squaliformes: Squalidae) in the Caribbean Coast of Central America. *Uniciencia* 31(2): 69–82. doi:10.15359/ru.31-2.5

Compagno L.J.V. (2001) *Sharks of the World. An Annotated and Illustrated Catalogue of Shark Species Known to Date: Volume 2 Bullhead, Mackerel and Carpet Sharks (Heterodontiformes, Lamniformes and Orectolobiformes).* FAO Species Catalogue for Fishery Purposes No. 1. Volume 2. Rome, Italy: Food and Agriculture Organization of the United Nations.

Compagno L.J.V. (1988) *Sharks of the Order Carcharhiniformes*. Princeton, New Jersey: Princeton University Press.

Compagno L.J.V. (1984) *Sharks of the World. An Annotated and Illustrated Catalogue of Shark Species Known to Date: Part 1 Hexanchiformes to Lamniformes.* FAO Species Catalogue Volume 4 Part 1. Rome, Italy: Food and Agriculture Organization of the United Nations.

Dudgeon C.L., Simpfendorfer C., Pillans R.D. (2019) *Stegostoma fasciatum* (amended version of 2016 assessment). *The IUCN Red List of Threatened Species 2019*: e.T41878A161303882. doi:10.2305/IUCN.UK.2019-3.RLTS.T41878A161303882.en

Dudgeon C.L., Coulton L., Bone R., Ovenden J.R., Thomas S. (2017) Switch from sexual to parthenogenetic reproduction in a zebra shark. *Scientific Reports* 7: 40537. doi:10.1038/srep40537

Dudgeon C.L., Broderick D., Ovenden J.R. (2009) IUCN classification zones concord with, but underestimate, the population genetic structure of the zebra shark *Stegostoma fasciatum* in the Indo-West Pacific. *Molecular Ecology* 18(2): 248–261. doi:10.1111/j.1365-294X.2008.04025.x

Dudgeon C.L, Noad M.J., Lanyon J.M. (2008) Abundance and demography of a seasonal aggregation of zebra sharks *Stegostoma fasciatum. Marine Ecology Progress Series* 368: 269–281. doi:10.3354/meps07581

Ebert D.A., Ho H.C., White W.T., De Carvalho M.R. (2013) Introduction to the systematics and biodiversity of sharks, rays, and chimaeras (Chondrichthyes) of Taiwan. *Zootaxa* 3752(1): 5–19. doi:10.11646/zootaxa.3752.1.3

Henningsen A.D., Smale M., Garner R., Kinnunen N. (2004) Reproduction, embryonic development, and reproductive physiology of elasmobranchs. In: Smith M., Warmolts D., Thoney D., Hueter R. (eds.). *Elasmobranch Husbandry Manual: Captive Care of Sharks, Rays and their Relatives.* Columbus, Ohio: Ohio Biological Survey Inc., 227–236.

Kanaiwa M., Kimoto A., Yokawa K. (2011) *Standardized CPUE of Striped Marlin in North Western Central Pacific Ocean by Using GLM*. ISC/11/BILLWG-2/06 Working paper submitted to the ISC Billfish Working Group Meeting, 24 May–1 June 2011, Taipei, Taiwan.

Kousteni V., Kontopoulou M., Megalofonou P. (2010) Sexual maturity and fecundity of *Scyliorhinus canicula* (Linnaeus, 1758) in the Aegean Sea. *Marine Biology Research* 6(4): 390–398. doi:10.1080/17451000903233771

Kunze K., Simmons L. (2004) Notes on reproduction of the zebra shark, *Stegostoma fasciatum* in a captive environment. In: Smith M., Warmolts D., Thoney D., Hueter R. (eds.). *Elasmobranch Husbandry Manual: Captive Care of Sharks, Rays and their Relatives.* Columbus, Ohio: Ohio Biological Survey Inc., 493–498.

Lizama M.D.L.A.P., Ambrósio A.M. (2002) Condition factor in nine species of fish of the Characidae family in the upper Paraná River floodplain, Brazil. *Brazilian Journal of Biology* 62(1): 113–124. doi:10.1590/S1519-69842002000100014

Mohan P.J., Clark S.T., Schmid T.H. (2004) Age and growth of captive sharks. In: Smith M., Warmolts D., Thoney D., Hueter R. (eds.). E*lasmobranch Husbandry Manual: Captive Care of Sharks, Rays and their Relatives*. Columbus, Ohio: Ohio Biological Survey Inc., 201–226.

Oliveira M.R., Costa E.F.S., Araújo A.S., Pessoa E.K.R., Carvalho M.M., Cavalcante L.F.M., Chellappa S. (2012) Sex ratio and length-weight relationship for five marine fish species from Brazil. *Journal of Marine Biology and Oceanography* 1(2). doi:10.4172/2324-8661.1000103

Robinson D.P., Baverstock W., Al-Jaru A., Hyland K., Khazanehdari K.A. (2011) Annually recurring parthenogenesis in a zebra shark *Stegostoma fasciatum*. *Journal of Fish Biology* 79(5): 1376–1382. doi:10.1111/j.1095-8649.2011.03110.x

Schmid T.H., Murru F.L. (1994) Bioenergetics of the bull shark, *Carcharhinus leucas*, maintained in captivity. *Zoo Biology* 13(2): 177–185. doi:10.1002/zoo.1430130209

Toledo H., Callejas P., Alfaro A.H., Guimeráns H., Alonso E. (2022) Monitoring, training and diet of the zebra shark (*Stegostoma fasciatum*) at the aquarium of Loro Parque. *Drum and Croaker* 53: 48–55.

Toledo H., Alonso E. (2021) *Stegostoma fasciatum* breeding program at Loro Parque Aquarium*. Drum and Croaker* 52: 84–90.

Uchida S., Toda M., Kamei Y. (1990) Reproduction of elasmobranchs in captivity. In: Pratt Jr. H.L., Gruber S. H., Taniuchi T. (eds.). *Elasmobranchs as Living Resources: Advances in the Biology, Ecology, Systematics, and the Status of the Fisheries*. Springfield, VA: US Department of Commerce, 211–237.

Van Dykhuizen G., Mollet H.F. (1992) Growth, age estimation and feeding of captive sevengill sharks, Notorynchus cepedianus, at the Monterey Bay Aquarium. *Australian Journal of Marine and Freshwater Research* 43(1): 297–318.

Watson L., Janse M. (2017) Reproduction and husbandry of zebra sharks, *Stegostoma fasciatum*, in aquaria. In: Smith M., Warmolts D., Thoney D., Hueter R., Murray M., Ezcurra J. (eds.). *The Elasmobranch Husbandry Manual II: Recent Advances in the Care of Sharks, Rays and their Relatives*. Columbus, Ohio: Ohio Biological Survey Inc., 421–432.

White W.T., Last P.R., Stevens J.D., Yearsley G.K., Fahmi, Dharmadi (2006) *Economically Important Sharks and Rays of Indonesia. Canberra, Australia:* Australian Centre for International Agricultural Research.