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JZAR Research article

Research article

# Sustainable species management of the elasmobranch populations within European aquariums: a conservation challenge

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**Keywords:** conservation, elasmobranch, sustainable population

**Article history:**
Received: 28 Jun 2017
Accepted: 27 Sep 2017
Published online: 31 Oct 2017

## Abstract

Elasmobranchs, including sharks and rays, are popular animals in public aquariums. Worldwide, more than 700 million people visit zoos and aquariums annually, enabling elasmobranchs to become an important ambassador for their natural habitats. We conducted a census within the European Association of Zoos and Aquaria to gain a better overview of which species are present within European collections. The census showed that 102 chondrichthyan species are found in European zoos and public aquariums, accounting for 8.6% of all known species. Benthic species are the most common. Of the captive population, 47.1% of species have reproduced in aquariums. Of the reproducing species, 87.8% exhibit body sizes of 51 to 250 cm. Categorising the reproductive results by reproductive mode, the most successful are oviparous and aplacental viviparous groups with uterine villi or trophonemata. A regional collection plan, stating the level of organised breeding recommended within the region, has been defined using the results of the census and the IUCN status. Currently, 42 species are managed by a species coordinator, within the ex-situ European elasmobranch population, to ensure a genetically healthy population, to increase reproductive output and to conduct husbandry research. Long-term breeding efforts will help to reduce the demand on wild populations to supply the aquarium population. Species coordinators will become the contact for in-situ conservation initiatives and international conservation bodies like IUCN. This study discusses further the future challenges in the captive management of chondrichthyan populations.

## Introduction

Elasmobranchs, including sharks and rays, are charismatic and popular animals at zoos and aquariums all over the world. With more than 700 million visitors annually passing through the gates of zoos and public aquariums of the world. Affiliated through regional associations, such as the European Association of Zoos and Aquaria (EAZA), and global associations, such as the World Association of Zoos and Aquariums (WAZA), these zoological facilities possess an unrivalled platform to engage the general public in education and conservation of this subclass of species (Penning et al. 2009; Gusset and Dick 2011; Barongi et al. 2015). Zoo and aquarium animals become ambassadors for their species and mascots for the habitats in which they live. Of the 1,188 chondrichthyan species (elasmobranchs and chimaera) in the wild (Weigmann, 2016), it is estimated that one quarter are threatened according to IUCN Red List criteria, due to overfishing (targeted and incidental) and habitat degradation. Large-bodied, shallow-water species, such as some elasmobranchs, are at greatest risk and five out of the seven most threatened families are rays (Dulvy et al. 2014). Increasingly, zoos and aquariums have become important for the conservation of threatened species, both directly through captive breeding programmes, and indirectly by improving our understanding of species' biology, behaviour and reproduction, which can aid conservation management in the wild (Barongi et al. 2015). To permit elasmobranch conservation, there is a need to change public perception about sharks, from the belief that we need to protect humans from sharks to the understanding that in fact we must protect sharks from humans (Simpfendorfer et al. 2011).

EAZA initiated, in collaboration with the European Union of Aquarium Curators (EUAC), the Elasmobranch Taxon Advisory Group (TAG). This TAG is part of the larger Fish and Aquatic Invertebrate TAG (FAITAG). In 2007, the first elasmobranch studbooks were initiated within Europe on blue-spotted stingray (*Taeniura lymma*, Forsskål, 1775) and zebra shark (*Stegostoma fasciatum*, Hermann, 1783). Soon afterwards the number of elasmobranch studbooks increased, which led to the official start of the elasmobranch TAG in 2013. Before planning any strategy on ex-situ population management, further knowledge on population statistics is necessary. Firchau and colleagues (2004) demonstrated the importance and value of a public aquarium elasmobranch census. Within the current study, an elasmobranch census was conducted in 2011 and in 2016, each covering the preceding five-year period, to review the captive populations in Europe.

The overall European elasmobranch census is a tool used to define the Regional Collection Plan (RCP). A decision tree, with specific conservation, education and research criteria (EAZA 2005) was used per species to compile the RCP. The main goal of the RCP is to identify which species should be collaboratively managed within a region on a population or individual level. Currently, two types of programmes are defined and used on elasmobranchs in aquariums: 1. European Studbook (ESB) and 2. Monitoring Programme (MON-P). An ESB manages the population on an individual level (with special software to register each animal) and recommendations are made within the ESB on animal transfers to maintain a genetically healthy population. Genetic research is used for paternity testing (e.g. Janse et al. 2013) and taxonomic issues. A less stringent form of management is the MON-P, which manages species at the population level. Both types of programmes are managed by one central species coordinator with the responsibility for collecting data and reporting on husbandry and health issues of the species.

The main research question on the census was to learn the current population trend of chondrichthyans in European aquariums. Below we discuss how the census results inform the RCP, which in turn will define the future management approaches towards the aquarium populations.

## Materials and methods

Two consecutive censuses were sent to 103 and 201 zoos and public aquaria in Europe, respectively. The first census in 2011 covered a five-year period 2006–2010, the second census in 2016 covered the next five years: 2011–2015. The second questionnaire was more extensive with the aim to build on the original data set (Table 1).

The census results over 2006-2015 were classified into five different reproduction modes, using the categories of Hamlett and Koop (1999) and Henningsen et al. (2013): 1. Oviparity (O); 2. Aplacental yolk sac viviparity (VA1); 3. Aplacental viviparity with uterine villi or trophonemata (VA2); 4. Aplacental viviparity with oophagy intrauterine cannibalism (VA3) and 5. Placental viviparity (VP). The results of the census were also categorised by lifestyle mode (Powell et al. 2004): 1. Benthic as a sedentary species with low metabolism, spending most of the time on the bottom; 2. Semi-pelagic as a free-swimming species, which periodically rest on the bottom; 3. Pelagic (non-obligate ram ventilator) can regulate buoyancy by swallowing air (e.g. *Odontaspidae*) and 4. Pelagic (obligate ram ventilator), swims constantly to create hydrodynamic lift to aid respiration and circulate body fluids. The maximum body size is used in the presentation of the results. For all elasmobranch species, the total body length is used, except for representatives of the stingrays (*Dasyatidae*) and skates (*Rajidae*), where the maximum wingspan is used in calculations. All body sizes are derived from FishBase (Froese and Pauly 2017), with a few exceptions defined in the overview.

Threatened species are defined as the total of the IUCN Red List categories critically endangered (CR), endangered (EN) and vulnerable (VU).

Data were analysed for all chondrichthyans combined (102 true species), as well as for sharks (47 species) and for rays and skates separately (53 species). Chimaeras were not analysed separately (only 2 species). The following variables were analysed: number of aquariums (n); ex-situ breeding, no or yes (0 or 1, respectively); total length (m); IUCN status (1–5 as LC to CR, with DD coded as


**Figure 1.** Map of European zoos and aquariums participating in the elasmobranch census.

**Table 1.** Overview of the questions featuring in the two different chondrichthyan censuses sent to European public aquariums (M=male; F=female; U=unknown).

| | 2006–2010 | 2011–2015 |
|---|---|---|
| Species kept in 5-year period | X | X |
| New species in 5-year period | X | X |
| Current population as of 31 December of last year (M:F:U) | X | X |
| Potential breeding pairs | | X |
| Whether species have been bred | X | X |
| Species bred in the last 5 years | X | X |
| Number of young in 5-year period (M:F:U) | X | X |
| Survival rate >3 months old (%) | | X |

**Table 2.** Number of chondrichthyan species (N), reproducing species ($N_r$, %) and specimens (n) kept and percentage of successful breeding of a species within the European aquarium population.

| Taxon | N ($N_r$, %) | | n | |
|---|---|---|---|---|
| | 2006–2010 | 2011–2015 | 2006–2010 | 2011–2015 |
| Sharks | 41 (53.7) | 47 (40.4) | 1936 | 2910 |
| Rays and skates | 50 (36.0) | 53 (52.8) | 1141 | 2177 |
| Chimaeras | 1 (100) | 2 (50.0) | 11 | 12 |
| Total | 92 (44.6) | 102 (46.7) | 3088 | 5099 |

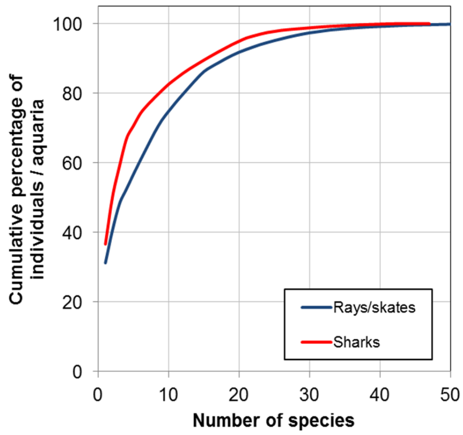


**Figure 2.** Distribution of aquarium population of elasmobranchs in Europe expressed as cumulative percentage of individuals as of 31 December 2015.

missing value); reproduction (1–5: OV, VA1, VA2, VA3, VP); and lifestyle (1–4: benthic, semi-pelagic, pelagic, ram pelagic). In order to explore the relationships between the measured variables, Kendall-tau non-parametric correlations were calculated.

## Results

Response rate from the census questionnaires was 66 (65% of total number of questionnaires sent out) and 110 (55%) (Figure 1), for 2006–2010 and 2011–2015, respectively. In both censuses, three aquariums answered as having no elasmobranchs in their collection. In the 2011–2015 census, 102 different species were found in 110 public aquariums in Europe (Table 2), of which four species were no longer held by the end of the census period. In the same period, 46.7% of species were reproducing successfully in European zoos and aquariums; over the whole 2006–2015 period this was 47.1%.

The representation of species within aquariums is uneven (Figure 2). Eight species of shark and 13 species of rays and skates make up 80% of all individuals of these groups kept in European aquariums; and 18 species of rays and skates comprise the collections of 80% of all aquariums.

The number of shark and skate/ray species per aquarium (Figure 3A) was not more than four in 50% of the aquariums, although there are aquariums with up to 12 ray and skate species and up to 20 shark species. More than 50% of the aquariums have no more than 20 individual rays and skates and a maximum of 40 sharks. A few aquariums have up to 160 rays and skates and up to

**Table 3.** Kendall-tau non-parametric correlations in shark and ray/skate life histories within European public aquariums, where n is number of specimens and $N_{aq}$ is number of aquariums (Reprod. = Reproduction).

| | n | $N_{aq}$ | Breeding in aquariums | Size | IUCN | Reprod. |
|---|---|---|---|---|---|---|
| Sharks | | | | | | |
| $N_{aq}$ | 0.767 | | | | | |
| Breeding in aquariums | 0.384 | 0.334 | | | | |
| Size | -0.008 | 0.099 | -0.351 | | | |
| IUCN | 0.008 | -0.003 | -0.088 | 0..85 | | |
| Reprod. | -0.138 | -0.010 | -0.501 | 0.603 | 0.294 | |
| Lifestyle | -0.087 | 0.039 | -0.452 | 0.493 | 0.208 | 0.771 |
| Ray and Skates | | | | | | |
| $N_{aq}$ | 0.753 | | | | | |
| Breeding in aquariums | 0.602 | 0.618 | | | | |
| Size | -0.098 | -0.088 | -0.282 | | | |
| IUCN | -0.082 | -0.022 | -0.286 | 0.433 | | |
| Reprod. | -0.062 | -0.074 | -0.033 | -0.150 | -0.095 | |
| Lifestyle | 0.193 | 0.065 | 0.107 | 0.197 | -0.050 | 0.322 |

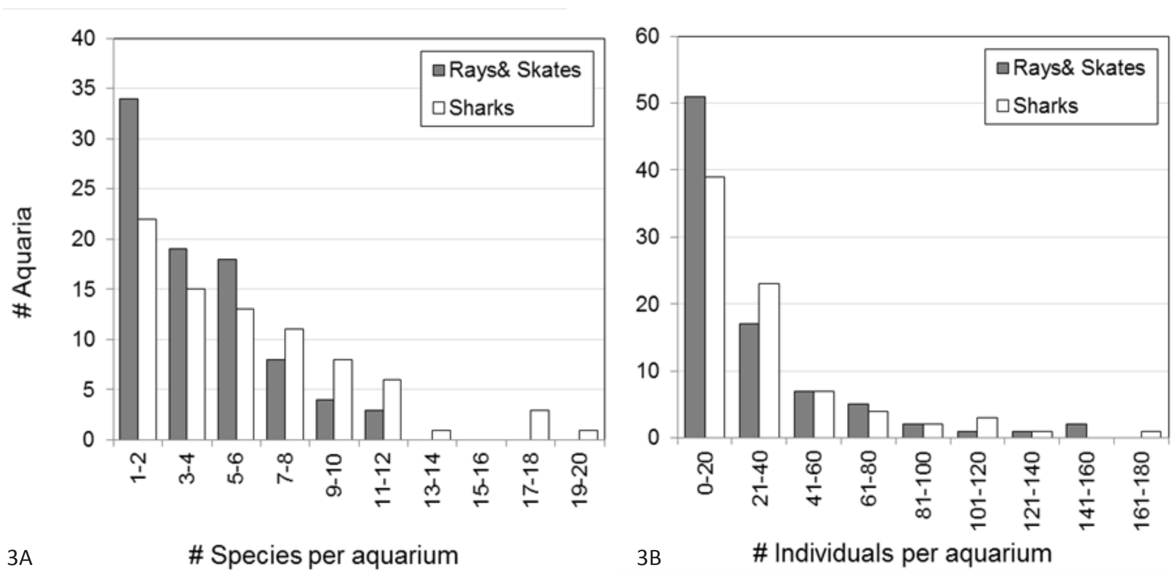


**Figure 3**. Number of elasmobranchs within Europe aquariums expressed as number of species (3A) and number of individuals (3B) per aquarium as of 31 December 2015.

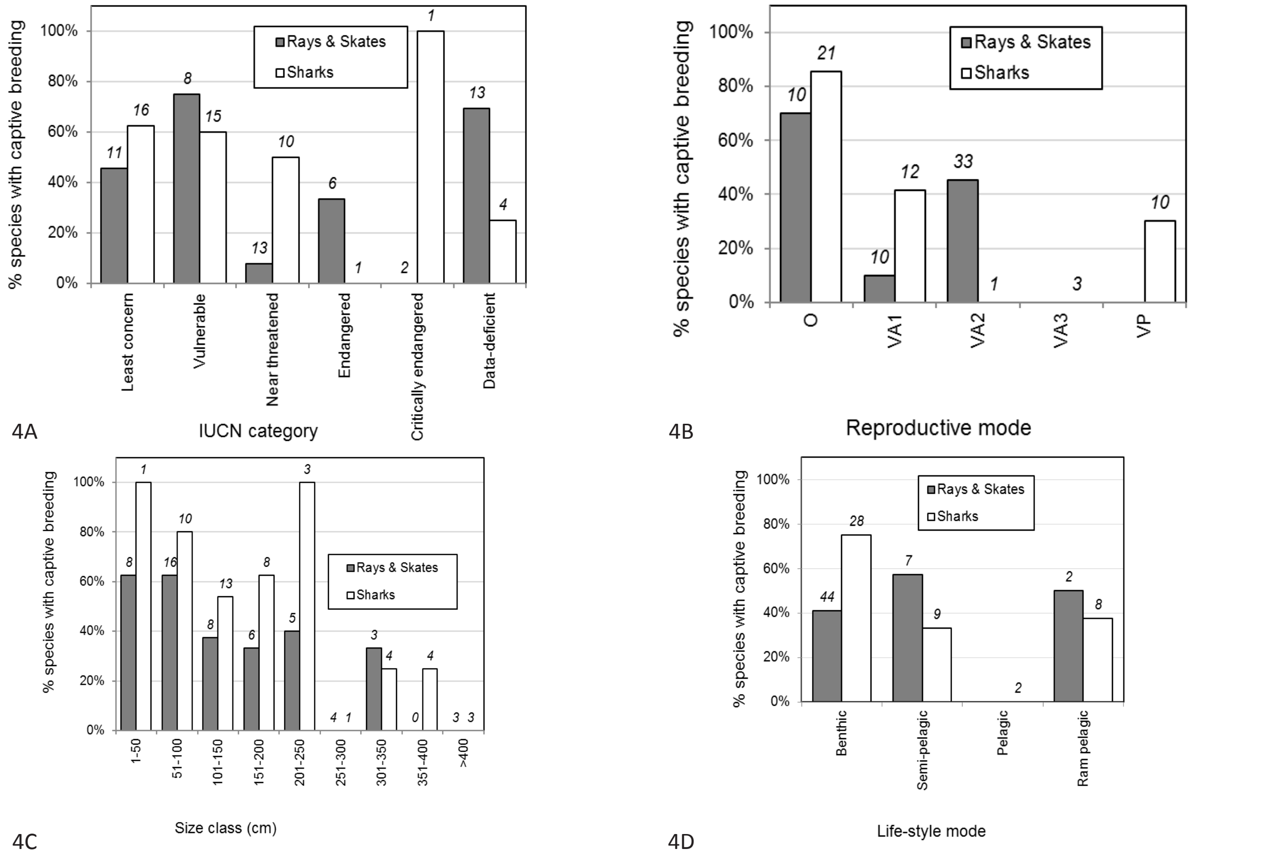


**Figure 4.** Success of ex-situ breeding (%) in European public aquariums as a function of IUCN Red List category (4A; τ=–0.286 for rays and skates; τ=non-significant for sharks), reproductive mode (4B; τ=non-significant; τ=–0.501 for sharks), size class (4C; τ=–0.282 for rays and skates; τ=–0.351 for sharks), lifestyle mode (4D; τ=non-significant for rays and skates; τ=–0.452 for sharks). Numbers in graphs indicate the total number of species per category.

180 individual sharks (Figure 3B).

Comparing the number of ex-situ (n=102) with in-situ chondrichthyan species (n=1188) (Weigmann 2016) reveals that 8.6% of all species were being kept in European aquariums in 2015. Also, considering the total number of chondrichthyan species featuring on the IUCN Red List (n=1048) (Dulvy et al. 2014), the census results revealed that 33 (18.2%) threatened species were being kept. An overview of the breeding success as a function of the IUCN Red List category is given in Figure 4A.

Successful reproduction occurred in 44.6% and 47.1% of species (n=102) for 2006–2010 and 2011–2015, respectively. Seven species were bred in 2006–2010 but not in the subsequent five years, while in the second census period, 14 new species were bred. In total, 55 species were bred in public aquariums in the period 2006–2015. In the second period, every aquarium was asked if they had potential breeding pairs of the species. In total, 72 species (67.3%) had potential breeding pairs, while 35 species (32.7%) had none. Of the 72 species with potential breeding pairs, 48 species (66.7%) were breeding successfully and 24 species (33.3%) have potential breeding pairs without successful breeding, at the time of the census.

The overall results of both censuses over the period 2006 to 2015 were classified into five different reproduction modes (Figure 4B and Table 4). The most successful reproductive category in aquariums is in the oviparous elasmobranchs with 60.0% of all species in this category reproducing. The second most reproductively successful is the category of aplacental viviparity (VA2) with uterine villi or trophonemata at 42.9%. The oviparous species group within this census contains all the chimaera, bamboo sharks (*Hemiscylliidae*), cat sharks (*Scyliorhinidae*), zebra sharks (*Stegostomatidea*), nurse sharks (*Ginglymostomatidae*) and skates (*Rajidae*). The VA2 category in this census includes the members of the whiptail stingrays (*Dasyatidae*), river stingrays (*Potamotrygonidae*) and both eagle and manta rays (*Myliobatidae*).

The results of the 2006–2015 census were categorised into maximum body size ranges per species (Table 4). When comparing the body size of animals with reproductive success (expressed in percentage of all species) the most successful body size range is 51–100 cm (Figure 4C) in absolute figures. Of all the species that are reproducing, 87.8% fall in the body size range of 51 to 250 cm.

The results of the second census (2006–2015) were also categorised by lifestyle mode (Powell et al. 2004) (Figure 4D and Table 4). The most common species kept in European aquariums are benthic species (70.6%). Also, benthic species constituted the most successful reproducing lifestyle mode (38.2%), especially for sharks (Figure 4D).

The number of specimens and aquariums correlates strongly with the success of ex-situ breeding in rays and skates, and little less for sharks (Table 3). There is a strong positive correlation between size and IUCN status: the larger species are more threatened. Size is negatively correlated with successful breeding of elasmobranchs in aquariums. Furthermore, in sharks, there is a strong positive correlation between reproductive mode and

**Table 4.** Overview of the European aquarium chondrichthyan census as number of animals on 31 December 2015 (n), number of aquariums keeping the species ($N_{aq}$), ex-situ breeding in the period 2006–2015, IUCN status, programme type, maximum body size (as total length TL or wingspan WS marked with *), and reproductive and lifestyle mode.

| Species | n | $N_{aq}$ | Captive breeding | IUCN | Programme | TL or WS(*) (cm)[1] | Reproductive mode | Lifestyle mode |
|---|---|---|---|---|---|---|---|---|
| *Aetobatus ocellatus* | 44 | 11 | Y | NT | ESB | 330*[2] | VA2 | S-P |
| *Aetomylaeus bovinus* | 8 | 4 | N | DD | MON-P | 220* | VA2 | S-P |
| *Amblyraja radiata* | 11 | 4 | Y | VU | | 105 | O | B |
| *Atelomycterus macleayi* | 2 | 1 | Y | LC | | 60 | O | B |
| *Atelomycterus marmoratus* | 36 | 10 | Y | NT | MON-P | 70 | O | B |
| *Bathytoshia brevicaudata* | 2 | 1 | N | LC | | 210*[3] | VA2 | B |
| *Carcharhinus acronotus* | 5 | 3 | N | NT | | 200 | VP | P+ |
| *Carcharhinus amblyrhynchos* | 2 | 10 | N | NT | | 255 | VP | P+ |
| *Carcharhinus leucas* | 0 | 1 | N | NT | | 360 | VP | P+ |
| *Carcharhinus melanopterus* | 261 | 55 | Y | NT | ESB | 200 | VP | P+ |
| *Carcharhinus plumbeus* | 70 | 18 | Y | VU | ESB | 250 | VP | P+ |
| *Carcharias taurus* | 36 | 16 | N | VU | MON-P | 330 | VA3 | p- |
| *Cephaloscyllium ventriosum* | 2 | 3 | Y | LC | | 110 | O | B |
| *Chiloscyllium arabicum* | 0 | 1 | Y | NT | | 80 | O | B |
| *Chiloscyllium griseum* | 31 | 5 | Y | NT | | 77 | O | B |
| *Chiloscyllium plagiosum* | 104 | 14 | Y | NT | | 83 | O | B |
| *Chiloscyllium punctatum* | 230 | 33 | Y | NT | | 132 | O | B |
| *Chiloscyllium* sp. | 18 | 1 | N | NE | | - | O | B |
| *Chimaera phantasma* | 2 | 1 | N | DD | | 100 | O | S-P |
| *Dasyatis pastinaca* | 86 | 24 | Y | DD | MON-P | 60* | VA2 | B |
| *Dasyatis thetidis* | 1 | 1 | N | LC | | 200*[3] | VA2 | B |
| *Fluvitrygon oxyrhyncha* | 1 | 1 | N | EN | | 36* | VA2 | B |
| *Galeorhinus galeus* | 0 | 1 | N | VU | MON-P | 195 | VA2 | S-P |
| *Ginglymostoma cirratum* | 55 | 26 | N | DD | MON-P | 430 | VA1 | B |
| *Glaucostegus cemiculus* | 75 | 13 | Y | EN | MON-P | 242 | VA1 | B |
| *Glaucostegus granulatus* | 1 | 1 | N | VU | | 280 | VA1 | B |
| *Glaucostegus typus* | 13 | 9 | N | VU | | 270 | VA1 | B |
| *Haploblepharus edwardsii* | 6 | 1 | N | NT | | 59 | O | B |
| *Haploblepharus pictus* | 5 | 1 | Y | LC | | 57 | O | B |
| *Hemiscyllium ocellatum* | 58 | 28 | Y | LC | MON-P | 107 | O | B |
| *Heterodontus francisci* | 46 | 15 | Y | DD | ESB | 122 | O | B |
| *Heterodontus japonicus* | 3 | 2 | N | LC | | 120 | O | B |
| *Heterodontus portusjacksoni* | 33 | 12 | Y | LC | | 165 | O | B |
| *Heterodontus zebra* | 5 | 5 | Y | LC | | 125 | O | B |
| *Himantura uarnak* | 20 | 11 | N | VU | MON-P | 200* | VA2 | B |
| *Himantura undulata* | 12 | 4 | N | VU | | 130*[2] | VA2 | B |
| *Hydrolagus colliei* | 10 | 3 | Y | LC | MON-P | 100 | O | S-P |
| *Hypanus americana* | 94 | 23 | Y | DD | MON-P | 200* | VA2 | B |
| *Leucoraja naevus* | 11 | 3 | Y | LC | | 71 | O | B |
| *Maculabatis gerrardi* | 1 | 1 | N | VU | | 90*[3] | VA2 | B |
| *Mobula mobular* | 1 | 1 | N | EN | | 520* | VA2 | P+ |
| *Mustelus asterias* | 110 | 23 | Y | LC | MON-P | 140 | VA1 | S-P |

**Table 4.** Overview of the European elasmobranch census (continued).

| Species | n | $N_{aq}$ | Captive breeding | IUCN | Programme | TL or WS(*) (cm)[1] | Reproductive mode | Lifestyle mode |
|---|---|---|---|---|---|---|---|---|
| *Mustelus californicus* | 2 | 2 | N | LC | | 124 | VA1 | S-P |
| *Mustelus mustelus* | 40 | 13 | Y | VU | MON-P | 200 | VA1 | S-P |
| *Myliobatis aquila* | 94 | 16 | Y | DD | MON-P | 183* | VA2 | S-P |
| *Nebrius ferrugineus* | 4 | 4 | N | VU | | 320 | VA3 | B |
| *Negaprion acutidens* | 0 | 1 | N | VU | | 380 | VP | S-P |
| *Negaprion brevirostris* | 9 | 5 | N | NT | | 340 | VP | S-P |
| *Neotrygon kuhlii* | 51 | 19 | Y | DD | ESB | 30*[5] | VA2 | B |
| *Odontaspis ferox* | 4 | 2 | N | VU | | 450 | VA3 | P- |
| *Orectolobus hutchinsi* | 3 | 1 | N | LC | | 149 | VA1 | B |
| *Orectolobus japonicus* | 3 | 2 | N | DD | | 118 | VA1 | B |
| *Orectolobus maculatus* | 9 | 6 | Y | LC | | 320 | VA1 | B |
| *Pateobatis fai* | 1 | 1 | N | VU | | 186*[4] | VA2 | B |
| *Poroderma africanum* | 44 | 5 | Y | NT | | 101 | O | B |
| *Poroderma pantherinum* | 5 | 1 | N | DD | | 84 | O | B |
| *Potamotrygon castexi* | 2 | 2 | N | DD | | 60* | VA2 | B |
| *Potamotrygon falkneri* | 2 | 2 | N | DD | MON-P | 60* | VA2 | B |
| *Potamotrygon henlei* | 4 | 1 | N | LC | | 45* | VA2 | B |
| *Potamotrygon leopoldi* | 55 | 13 | Y | DD | MON-P | 40* | VA2 | B |
| *Potamotrygon motoro* | 205 | 34 | Y | DD | MON-P | 50* | VA2 | B |
| *Potamotrygon motoro x hystrix6* | 1 | 2 | N | DD | | - | VA2 | B |
| *Potamotrygon orbignyi* | 15 | 7 | Y | LC | | 35* | VA2 | B |
| *Potamotrygon hystrix* | 1 | 1 | N | DD | | 40* | VA2 | B |
| *Potamotrygon itaituba P14* | 0 | 1 | N | NE | | ? | VA2 | B |
| *Prionace glauca* | 0 | 1 | N | NT | | 400 | VA1 | P+ |
| *Pristis pristis* | 4 | 3 | N | CR | ESB | 700 | VA1 | B |
| *Pristis zijsron* | 2 | 1 | N | CR | ESB | 730 | VA1 | B |
| *Pseudoginglymostoma brevicaudatum* | 26 | 10 | Y | VU | MON-P | 75 | O | B |
| *Pteroplatytrygon violacea* | 59 | 19 | Y | LC | MON-P | 96* | VA2 | P+ |
| *Raja asterias* | 17 | 1 | N | NT | | 70 | O | B |
| *Raja brachyura* | 23 | 15 | Y | NT | MON-P | 125 | O | B |
| *Raja clavata* | 686 | 44 | Y | NT | MON-P | 139 | O | B |
| *Raja microocellata* | 87 | 18 | Y | NT | MON-P | 86 | O | B |
| *Raja miraletus* | 2 | 1 | N | LC | | 63 | O | B |
| *Raja montagui* | 50 | 19 | Y | LC | MON-P | 80 | O | B |
| *Raja* sp. | 1 | 1 | N | NE | | - | O | B |
| *Raja undulata* | 167 | 32 | Y | EN | MON-P | 100 | O | B |
| *Rhina ancylostoma* | 9 | 10 | N | VU | MON-P | 300 | VA1 | B |
| *Rhinobatos rhinobatos* | 25 | 10 | N | EN | MON-P | 147 | VA1 | B |
| *Rhinoptera bonasus* | 90 | 17 | Y | NT | MON-P | 213* | VA2 | S-P |
| *Rhinoptera javanica* | 29 | 4 | N | VU | | 150* | VA2 | S-P |
| *Rhinoptera jayakari* | 25 | 2 | Y | DD | | ? | VA2 | S-P |

**Table 4.** Overview of the European elasmobranch census (continued).

| Species | n | $N_{aq}$ | Captive breeding | IUCN | Programme | TL or WS(*) (cm)[1] | Reproductive mode | Lifestyle mode |
|---|---|---|---|---|---|---|---|---|
| *Rhinoptera jayakari* | 25 | 2 | Y | DD | | ? | VA2 | S-P |
| *Rhinoptera marginata* | 16 | 1 | N | NT | | 200* | VA2 | S-P |
| *Rhynchobatus djiddensis* | 6 | 3 | N | VU | | 310 | VA1 | B |
| *Rhynchobatus australiae* | 1 | 1 | N | VU | | 300 | VA1 | B |
| *Rostroraja alba* | 2 | 2 | N | EN | | 230 | O | B |
| *Scyliorhinus canicula* | 1070 | 57 | Y | LC | | 100 | O | B |
| *Scyliorhinus stellaris* | 393 | 41 | Y | NT | MON-P | 170 | O | B |
| *Scyliorhinus torazame* | 1 | 2 | Y | LC | | 50 | O | B |
| *Sphyrna lewini* | 17 | 7 | N | EN | MON-P | 430 | VP | P+ |
| *Sphyrna tiburo* | 16 | 10 | N | LC | MON-P | 150 | VP | P+ |
| *Squalus acanthias* | 14 | 5 | Y | VU | | 160 | VA1 | B |
| *Squatina squatina* | 3 | 1 | Y | CR | MON-P | 244 | VA1 | B |
| *Stegostoma fasciatum* | 61 | 28 | Y | VU | ESB | 354 | O | B |
| *Taeniura grabata* | 6 | 1 | Y | DD | | 100* | VA2 | B |
| *Taeniura lymma* | 49 | 24 | Y | NT | ESB | 35* | VA2 | B |
| *Taeniurops meyeni* | 10 | 2 | N | VU | | 330 | VA2 | B |
| *Torpedo marmorata* | 3 | 4 | Y | DD | | 100 | VA2 | B |
| *Torpedo* sp. | 0 | 1 | N | DD | | - | VA2 | B |
| *Triaenodon obesus* | 34 | 19 | Y | NT | | 213 | VP | S-P |
| *Triakis scyllium* | 28 | 8 | N | LC | | 150 | VA1 | S-P |
| *Triakis semifasciata* | 32 | 7 | N | LC | MON-P | 198 | VA1 | S-P |
| *Trygonorrhina fasciata* | 1 | 1 | N | LC | | 126 | VA1 | B |
| *Urobatis jamaicensis* | 6 | 4 | Y | LC | | 76 | VA2 | B |
| *Urogymnus granulata* | 4 | 3 | N | VU | | 141* | VA2 | B |
| *Urolophus halleri* | 3 | 1 | N | LC | | 58 | VA2 | B |

[1]All figures are derived from FishBase (Froese and Pauly 2017), with a few exceptions: [2]Last et al. (2010); [3]Compagno et al. (1989); [4]White et al. (2006); [5]Last et al. (2016); [6]hybrid.

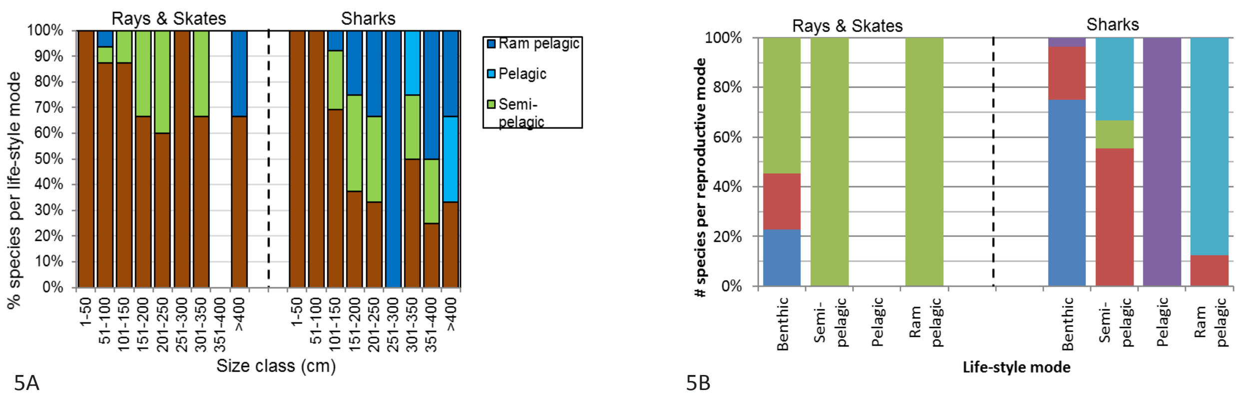


**Figure 5**. Relationship between reproductive mode and body size class (5A) and lifestyle mode (5B) in the elasmobranch population of European public aquariums.

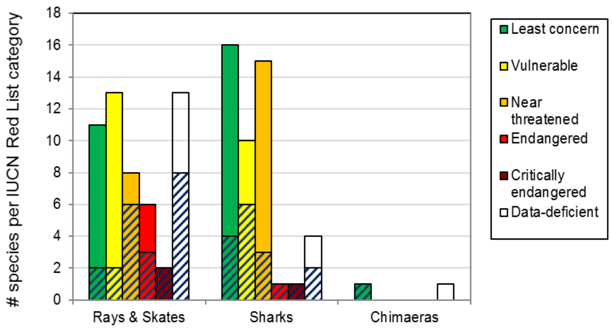


**Figure 6.** Aquarium populations of chondrichthyans in Europe categorised by each species' IUCN status. The shaded bars represent the number of species in an organised European breeding programme within the IUCN Red List category.

lifestyle and body size: the larger the species, the more likely it is to be ram pelagic and to demonstrate placental viviparity (Figure 5A). Ram-pelagic species are more difficult to breed in aquariums.

Combining the reproductive mode with size class (Figure 5A) or lifestyle mode (Figure 5B) illustrates the dispersal of the different reproductive modes of the European aquarium population.

The RCP of the European chondrichthyans currently consists of nine studbook programmes (ESB) and 32 monitoring programmes (MON-P) (Table 4). This means that 40.2% of the chondrichthyan species kept in Europe are currently managed in a breeding programme. When combining the RCP with the different IUCN Red List categories, it is clear that species within the threatened categories are more important for ex-situ management than species from a lower IUCN category (Figure 6).

## Discussion

The results of the censuses give a representative overview of the elasmobranch population in European zoos and public aquariums, even though not all institutions participated. This study shows that 8.6% of species of the wild are kept in European aquariums. Henningsen et al. (2004) gives an overview of worldwide chondrichthyan reproduction in captivity, with a total of 100 species being described. Compared to the results of the current census, where 55 species are bred in European public aquariums, some differences are found: 1. 15 additional species are bred within the European ex-situ population compared to the worldwide study, eight of which are endemic to European waters; and 2. 19 species have not yet been bred in Europe compared to the worldwide captive reproductive list. This shows the potential for breeding new species within European aquariums. This is supported when looking at the potential breeding pairs, whereby 24 species have potential breeding pairs, but no successful breeding up to now. Also, 35 species do not yet have breeding pairs, due to single specimens, restricted total number of animals in captivity (<5), single-sex populations or immature animals being maintained in one enclosure. Both parameters need to be addressed in the future to increase breeding success. Although good programme management will help with this, individual institutions should become more strategic in their institutional collection planning to ensure appropriate sex ratios are maintained to maximise breeding opportunities. Bilateral initiatives of animal exchange will also help to improve breeding success. It should also be considered that some species may need to be actively managed to prevent breeding, particularly if they are already represented in large numbers across aquariums or they need very specific facilities to successfully breed that are not currently in place. To maintain genetic diversity within studbooks, zoos and aquariums will need to prioritise which animals to breed and this may also lead to maintaining groups that will not be required to breed.

Species in European aquariums which are CITES listed are restricted to *Pristis pristis* (Linnaeus, 1758) and *P. zijsron* (Bleeker, 1851) for Appendix I and *Sphyrna lewini* (Griffith and Smith, 1834) for Appendix II (CITES, 2017). All three species are in a managed programme but, to date, are not breeding in European aquariums (Table 4). The RCP needs revision on a regular basis. Three species of the IUCN Red List category 'endangered' are not yet managed: *Fluvitrygon oxyrhyncha* (Sauvage, 1878) (n=1), *Mobula mobula* (Bonnaterre, 1788) (n=1) and *Rostroraja alba* (Lacepède, 1803) (n=2), due to the limited number of individuals present in European collections. Other species which are not in the RCP are sometimes very common and easy to breed (e.g., Scyliorhinus canicula, Linnaeus, 1758) which would suggest that collaborative management is not a first priority. However, having meta populations of these species at several institutions, if they are to remain a feature in our aquarium collections, would ensure genetically stronger populations, maintaining at least 90% gene diversity (Lacey 2013). Creating priority species ensures greater attention is given and space allocated to threatened species. When considering multiple species from one genera it might be more efficient to concentrate only on a few species. An illustrative example is with the *Aetobatus* genus, where *A. ocellatus* (Kuhl, 1823) is a managed studbook in Europe and *A. narinari* (Euphrasen, 1790) in North America. It is advised to not keep *A. narinari* in a European public aquarium to avoid further reducing the limited space for *A. ocellatus* in European collections (M. Janse, personal communications). In the IUCN Red List category 'Vulnerable', more species might be suitable for a programme in the future. A large portion of elasmobranch species are in the IUCN Red List category 'Data Deficient', so possibly more species will need attention after updated evaluations.

The programmes which are established for the most threatened species are not just for maintaining insurance populations ex-situ but also for investigating these species' requirements in the wild that might aid in-situ conservation efforts.

Dulvy et al. (2014) defined the most threatened elasmobranch families as sawfishes (*Pristidae*), angel sharks (*Squatinidae*), wedgefishes (*Rhynchobatidae*), sleeper rays (*Narkidae*), stingrays (*Dasyatidae*), guitarfishes (*Rhinobatidae*) and thresher sharks (*Alopiidae*). Except for the stingrays (15 species in this study), wedgefishes (2 species) and guitarfishes (7 species) only a few representatives of the other endangered families are found in European zoos and aquariums: e.g., *Pristis pristis*, *P. zijsron* and *Squatina squatina* (Linnaeus, 1758). These three species are managed in ex-situ programmes. Currently all three species are in insufficient numbers to ensure long-term population survival in captivity. The two wedgefish species, *Rhynchobatus australiae* (Whitley, 1939) (n=1) and *R. djiddensis* (Forsskål, 1775) (n=6), are too limited in number to be managed. Whilst it is not always possible to maintain the most endangered elasmobranchs in captivity, they should still be the priority for conservation via awareness-raising in zoos or aquariums.

Sustainable breeding programmes are a great tool to ensure healthy captive populations and to improve husbandry standards (Penning et al. 2009). Numerous husbandry and health issues are compiled by species coordinators, which increases the overall knowledge of the managed species. Biological, physiological and ethological information has been compiled for many years from ex-situ elasmobranch research which can provide important support information for in-situ conservation work on threatened species (Tlusty et al. 2017), not only to share husbandry information or to exchange animals, but also to create a global collection plan. The number of available aquariums is limited, so if every region were to prioritise the species on their RCP, an improved coverage of species can be made within the global zoo and aquarium community. Globally managed programmes must be carefully considered in order to ensure that the benefits of maintaining a larger number of meta populations is weighed up against the cost of international animal transfer, including fees for permits, and expeditious transport to minimise risks.

According to the censuses, 47.1% of species were reproducing successfully in aquariums in 2015. The most successful reproductive categories were the oviparous and aplacental viviparity with uterine villi or trophonemata. When analysing body size data, the reproductive success was greatest within a range of 51–100 cm. Benthic species proved to be most abundant species in aquariums. They are typically the smaller species. The reason smaller and oviparous species are more success is many-fold. All oviparous species are dermersal, and most are small (<100 cm) (Musick and Ellis 2005). Smaller species are generally easier to keep in aquariums and are mostly benthic species, so there is a reduced requirement for a large swimming space compared to (semi) pelagic species. Oviparity means these animals do not have long internal gestation periods. During gestation periods, viviparous species are more vulnerable to incidents that could affect survival of the embryo. Annual fecundity of oviparous species is much higher than viviparous species of comparable size (Musick and Ellis 2005). However, in viviparity the maternal contribution during development leads to the production of larger, less vulnerable offspring (Conrath and Musick 2012). Eggs can easily be removed from an exhibit before they hatched, whereas in viviparity there is a risk of predation within an exhibit. Aquarists get a chance to refine methods of egg hatching as they will often get multiple eggs and can practice, whereas the long gestation times between reproductive episodes in viviparous species can make learning a slow process.

A variety of reasons were reported for the potential cause of limited reproduction including: age, wrong group size, single-sex groups, different subspecies, confinement and compatibility stress, nutrition imbalance, water quality, health issues and a lack of seasonal or natural cues. Some of these challenges can easily be solved by having a well-managed collaborative breeding programme. Future in-situ as well as ex-situ research is necessary to increase health and husbandry knowledge, as is an enhanced collaboration with other zoological regions and the scientific community. Programme coordinators should compile husbandry issues and publish their results in scientific journals or husbandry manuals (e.g. Smith et al. 2004) to ensure a solid base and overview of the current knowledge from which further steps can be taken.

Organised breeding programmes have the potential to develop into sustainable, genetically healthy populations. However, new challenges will arise when managing aquatic animal populations. Genetic research of captive elasmobranch populations is important, including paternity testing, kinship and addressing taxonomic challenges. Different studies have started working on these issues (e.g. Heist and Feldheim 2004; Janse et al. 2013) but a close collaboration with other scientific institutions will be necessary. Another future challenge is management of surplus in a bid to keep a genetically healthy population structure over time. In mammals, artificial insemination is a commonly-used technique, but is new to elasmobranch management. However, the first artificial insemination trials have been conducted (Luer et al. 2007); in the future, artificial insemination may have an important role to play in ex-situ species management and for reducing the risks associated with moving large animals.

Similarly, well managed population programmes must also have options for limiting reproduction when necessary. It may be necessary to prevent breeding in genetically overrepresented individuals to avoid saturating the small ex-situ population with the genes of a small number of animals. However, contraception is also a new field in elasmobranch management. Henningsen et al. (2004) mentions the use of gonadotropin releasing hormone (GnRH) agonist and antagonist as a successful reproductive inhibition tool in other vertebrates, but is not yet used in elasmobranchs.

Increased collaboration with conservation organisations working on elasmobranchs, such as the Shark Trust, the European Elasmobranch Association and the IUCN shark and ray specialist group, will help to refine priorities for ex-situ management and to ensure that information gathered from in-situ and ex-situ studies is complimentary and beneficial to the species in question (Penning et al. 2009). Also, there is potential for conservation reintroduction projects from captive bred animals (e.g., Conde et al. 2011). The global 2015-2025 strategy for conserving sharks and rays gives a useful framework of priorities for elasmobranchs collaborative conservation programs (Bräutigam et al. 2015). Finally, the educational outreach programmes provided by zoos and aquariums can support conservation activities as well as ex-situ programmes, by teaching audiences about elasmobranchs and the threats they face.

## Acknowledgement

The authors wish to thank all participants of both questionnaires. Also, we thank Beth Firchau for making it possible to use the species list of the elasmobranch census she has created before.

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