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Breeding and larval development of the Yellow-banded Pipefish *Dunckerocampus pessuliferus*, including an overview of the current zoo population: An approach towards sustainable captive populations

Nachzucht und Larvalentwicklung der Sulu-Seenadel *Dunckerocampus pessuliferus*, einschließlich eines Überblicks über die aktuelle Zoopopulation: Ein Ansatz in Richtung nachhaltige Bestände in Menschenhand

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Abstract

As guideline for increased *Dunckerocampus* breeding, based on *D. pessuliferus* as husbandry analogue, we oppose husbandry management, captive reproduction and larval development of the species in the State Museum of Natural History Karlsruhe, Germany, and in the Aquarium of the Cologne Zoo, Germany. We observed mating, during which eggs were attached to the male, lasting up to an hour. Juveniles hatched after eight days at sizes of 4-5 mm. Adult color pattern developed after three weeks and maturity was reached after six months, at total sizes of 10.5-11 cm. We present survival rates and provide recommendations for optimum feeding. We further performed a ZIMS (Zoological Information Management System) database analysis (in October 2016 and May 2018) and observed a recent increase in the keeping of *D. pessuliferus*

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with currently nine institutions in a global scale (five of them being in Europe) holding this species (with 43 individuals in total). As not all zoos enter their collection data into ZIMS, we also checked the website "Zootierliste" (http://www.zootierliste.de/) for locating additional species holdings in Germany and other countries in Europe, however, which also includes private zoos and animal rescue facilities. Entries on the website "Zootierliste" from May 2018 showed a total of 17 European institutions holding *D. pessuliferus*: In total ten institutions in Germany and seven institutions in different European countries. Six of the listed institutions from Germany and other European countries were not included in ZIMS. According to ZIMS, only two further species of the seven currently recognized *Dunckerocampus* species are held in zoos globally: *D. dactyliophorus* with 70 individuals distributed among 16 zoos in North America (10), Europe (5), and Africa (1), and *D. multiannulatus* with 4 individuals in only one institution in Europe. We emphasize the importance of breeding efforts of not yet or so far only rarely bred marine fish species as well as improved exchange of knowledge and available zoo stock between institutions including publication of husbandry management and breeding successes for more sustainable aquaristics.

Keywords: Syngnathiformes, Syngnathidae, *Dunckerocampus*, *D. pessuliferus*, behavior, development, reproduction, zoo biology, zoo holdings

Introduction

The Syngnathidae are a family of fishes which are characterized amongst others by the relatively long snout and an elongated body with a series of bony rings. They include the seahorses, the pipefishes, the pipehorses, and the leafy, ruby, and weedy seadragons, which mostly are marine species but also can be found in brackish or even fresh water. Usually they inhabit shallow water with the males carrying the eggs and incubating them until hatching (Nelson, 1994). According to Eschmeyer (2014), 57 genera are known containing 300 species, which have a wide distribution range, but most of them living in the tropics such as in the Indian or Pacific Ocean. The genus *Dunckerocampus* contains seven species (Froese & Pauly, 2018): the redstripe pipefish (*D. baldwini*), the broad-banded pipefish (*D. boylei*), the glowtail pipefish (*D. chapmani*), the ringed pipefish (*D. dactyliophorus*), the many-banded pipefish (*D. multiannulatus*), the naia pipefish (*D. naia*), and the yellow-banded pipefish (*D. pessuliferus*); in the World Register of Marine Species (WORMS) also *D. caulleryi* is given as a valid species, but it is not listed with specific status in FishBase. *Dunckerocampus* representatives occur within a wide distribution range in the Indo Pacific Ocean region (Froese & Pauly, 2018).

Dunckerocampus pessuliferus, formerly also referred to as *Doryrhamphus pessuliferus*, is a coastal marine pipefish with a maximum size of 16 cm that dwells in coral patches on sandy or muddy slopes at depths of 15-35 m. The species inhabits water around the Coral Triangle including the Philippines, Indonesia, and northwestern Australia. Since these fish are active cleaners, they remove crustacean parasites from other fishes (Dawson, 1985; Kuiter, 1998; Allen & Erdmann, 2012).

In the IUCN Red List of Threatened Species, *D. pessuliferus* is listed as Least Concern together with *D. baldwini*, *D. boylei*, *D. multiannulatus*, and *D. naia*, whereas the remaining species of *Dunckerocampus* are listed as Data Deficient (Pollom, 2016). However, *D. pessuliferus* is under threat from ongoing coral and habitat loss, degradation, traditional medicine and trade for use in aquariums (Bruno & Selig, 2007, Carpenter et al., 2008, Vincent et al., 2011, Normile, 2016).

To counteract such negative trend and in particular to promote sustainable aquaristics, we herein report about the successful zoo breeding of this species in the public aquarium sections

of the State Museum of Natural History Karlsruhe and of Cologne Zoo, both in Germany. As a practical guideline for improved and increased breeding we opposed both the husbandry management and reproduction successes of *D. pessuliferus* at both institutions. We further provide a description of the larval development and give an overview of zoological gardens keeping this species based on information obtained from the Zoological Information Management System database, an international record keeping database for zoological institutions, complemented with data from "Zootierliste".

Material and methods

Captive management at the State Museum of Natural History Karlsruhe

The first breeding pair of *Dunckerocampus pessuliferus* was purchased from a zoo shop (Kölle Zoo) in 2006.

Data acquisition started in 2008. At that time, the breeding pair was held in a circulation system consisting of six cylindrical tanks with sizes of H (height) 22 x R (radius) 66 cm each and two aquariums with an actual capacity of 130 l each, L (length) 100 x W (width) 40 x H 40 cm in size (see also Fig. 1, Tab. 1). Originally, the circulation system was built for the breeding of longsnout seahorses (*Hippocampus reidi*) which required a distinct current installation including a downstream at the edges of the tank.

The aquariums with a total capacity of 1.000 l were filled with a few artificial plastic *Vallisneria* and had a skimmer type AP 703 from "Deltec". Furthermore, two sides were covered with black PVC plates and four 40W spotlights and one 36W fluorescent tube were installed on top of the aquariums. Additionally, we equipped the aquariums with three fine pored suction

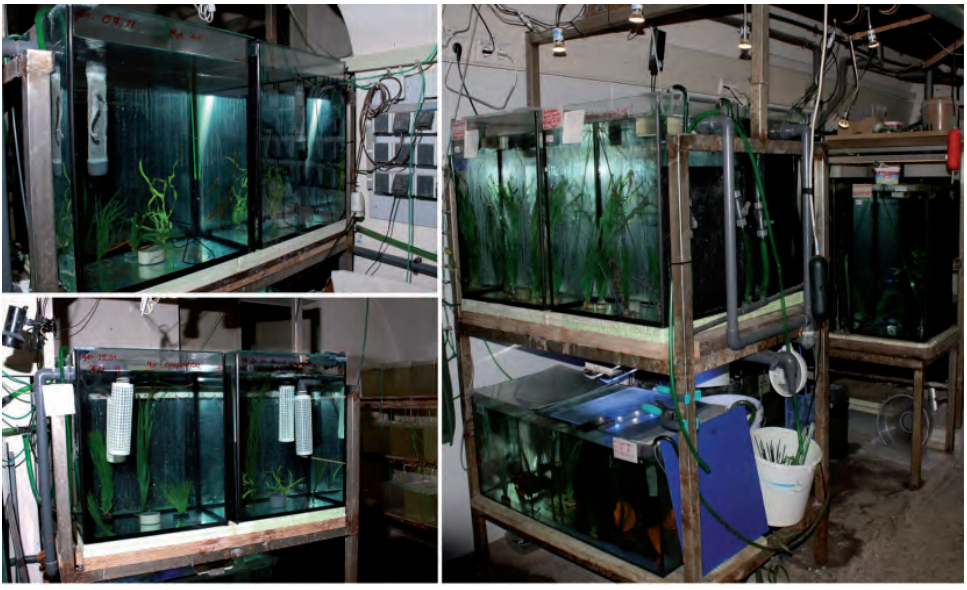

Fig. 1: Rearing tanks for *Dunckerocampus pessuliferus* at the State Museum of Natural History Karlsruhe, Germany: for juveniles (upper left), for larvae with fine pored mesh (lower left), and rearing tanks plus captive tanks for breeding pairs (right). Photos: J. Kirchhauser.

Tab. 1: Overview of husbandry parameters for *Dunckerocampus pessuliferus*.

	State Museum of Natural History Karlsruhe	Cologne Zoo
Aquarium sizes (LxWxH)	100 x 40 x 40 cm	60 x 40 x 40 to 120 x 60 x 60 cm
Cylindrical tank sizes (HxR)	66 x 22 cm	55 x 15 cm
Water temperature	26 °C	24-25 °C
Water parameters	NO_3^- 10-12.5 mg/l, PO_4^{3-} 0.25-0.34 mg/l	NO_3^- 10-25 mg/l, PO_4^{3-} 0,25-1 mg/l, carbonate hardness: 6, density: 1,024 g/cm³, salinity: 32-33 PSU
Equipment	skimmer type AP 703 ("Deltec"), black PVC-plates, 4x40W spotlights, 36W fluorescent tube, 2x18W UV-cleaner ("JBL"), 3 fine pored suction strainers type classic 600 ("Eheim")	3 skimmer ("Schuran") including biofilters, 6 x 54W T5 lamps ("Aqua Science"), 55W UV-cleaner ("Aqua Medic"), two heaters ("Sera"), SolarStinger SunStrip Marine 70 W lamp ("Econlux")
Decoration	plastic *Vallisneria*	plastic eel-, surf- and turtlegrass
Nourishment	copepods, *Artemia*, *Mysis*	*Brachionus*, copepods, *Artemia*, *Mysis*

strainers, type classic 600 of "Eheim", as well as pure wadding filling and a small bucket with holes including wadding for coarse dirt.

To avoid an infection with Hydrozoa, the aquariums and the interior were repeatedly sanitized within two weeks with fresh water for 24 hours each. In addition, the complete water system flowed through two 18W UV sterilization lights ("JBL") to control a resurgence of Hydrozoa and bacteria.

The tanks had a flow rate of 50 l per hour and a water temperature of 26 °C. On average, the NO_3^- (nitrate) value ranged between 10-12.5 mg/l and the PO_4^{3-} (phosphate) value ranged between 0.25-0.34 mg/l.

Two days prior to hatching the rearing aquariums were filled with saltwater and every 14 days the juveniles were transferred into a fresh water cleaned cylindrical tank to ensure a Hydrozoa free environment.

The male fish were transferred into the rearing tank when the eggs turned darker 1-2 days before hatching.

Captive management at Cologne Zoo

In October 2016, breeding was started with a pair of *Dunckerocampus pessuliferus* received from a zoo shop ("von Wussow") in July 2016 (at that time the female had a total length of 14 cm and the male of 14.5 cm).

They were kept in an aquarium with 330 l volume, a water temperature of 24-25 °C and measurements of L 120 x W 60 x H 60 cm with a skimmer ("Schuran") including a biofilter and two T5 54W lamps, type Aqua Science special ("Aqua Science") (see also Fig. 2, Tab. 1). For the progeny, we used three different aquarium systems. The first alternative was a small cuboid tank with 66 l linked to a system with 650 l, a skimmer ("Schuran"), a 55W UV-cleaner ("Aqua Medic"), two heaters ("Sera") and SolarStinger SunStrip Marine 70 W lamp ("Econlux"). The second option was a bigger cuboid tank with measurements of L 40 x W 60 x H 60 cm and an

Fig. 2: Keeping and rearing tanks for *Dunckerocampus pessuliferus* at the Cologne Zoo: Tank of the adult breeding pair (upper left), and different rearing tanks: cylindrical tanks (upper right), and cubical tanks (version 1, lower left, version 2, lower right). Photos: M. Pfeiffer.

actual capacity of 120 l linked to a system with more than 20,000 l. The tank was illuminated with one T5 Aqua Science duo and one T5 Aqua Science special both with 54W. As a third alternative, we used a cylindrical tank with measurements of H 55 x R 15 cm, actually including up to 40 l. Another tank was linked with the cylinder including 370 l and two T5 lamps with 54W Aqua Science special. The filtration was identical to the system of the breeding tank.

All tanks were arranged with different plastic eel-, surf- and turtlegrass, obtained from "Pangea Rocks", DK. The NO_3^- (nitrate) value in the parental aquarium was 10 mg/l and the PO_4^{3-} (phosphate) value was 1.0 mg/l with 6 °KH (carbonate hardness). The rearing aquarium had slightly different values with a 0.25 mg/l PO_4^{3-} (phosphate) value and the NO_3^- (nitrate) value was 25 mg/l. During the breeding process, we made various water changes with fresh saltwater and vacuumed the aquarium ground. The male yellow-banded pipefish was either transferred into the breeding tank one day before hatching, which was the main method, or the freshly hatched *D. pessuliferus* were transferred into the breeding tank shortly after hatching.

Nutrition

In Karlsruhe, the larvae and adult *Dunckerocampus pessuliferus* were nourished with self-raised copepods, *Artemia* and *Mysis*. In addition, the larvae in Cologne Zoo were fed with *Brachionus*. The living food was nourished with marine phytoplankton, *Spirulina* or dry food and enriched with INVE Selco® S.presso and S.parkle directly before they were provided to

the juvenile yellow-banded pipefishes. Moreover, Cologne Zoo purchased another species of copepods (*Tisbe*) from "Meerwassershop" and special small eggs of *Artemia* from "Ocean Nutrition". Those eggs were removed from the capsule with chlorine before hatching.

The aquariums were supplied with copepods two days before hatching so that the juveniles could find food immediately. In Cologne, we filled the tanks with phytoplankton and *Brachionus* and sieved 60-150 µm sized copepods for first feeding. Depending on size, they were fed daily up to six times.

The juveniles received increased quantities of food in the first few days. In Karlsruhe, they were provided with living copepods three times a day for the first two weeks. Afterwards they were fed with freshly hatched *Artemia* and as soon as possible with *Mysis*. After six months, they were nourished with frozen *Mysis*. At Cologne Zoo feeding took place with micro-*Artemia* (5th or 6th day) in addition to the feeding with copepods. Whilst the offspring gained in mass, the size of the living food likewise was adapted and changed from small copepods to *Artemia* and *Mysis*. The *Brachionus* and primary copepods were acquired from "Poseidon Aquaculture". Furthermore, another generation of *D. pessuliferus* in Karlsruhe was only fed with *Artemia* during larval development.

ZIMS and "Zootierliste" analyses

We analyzed 1) the species of *Dunckerocampus* held in zoos, 2) their individual numbers, and 3) the number of institutions currently keeping *D. pessuliferus* based on available data on living specimens from the ZIMS database. Our ZIMS analysis examined the status of the yellow-banded pipefish maintained in zoos both in Europe and abroad, and was performed in October 2016 and May 2018 based on available data on living specimens. Furthermore, we analyzed the current status of the remaining six species of *Dunckerocampus* recognized at time; this analysis was performed in May 2018.

Many zoos subscribe to and enter their collection data into ZIMS; however, the completeness of these data cannot be guaranteed, as some data may be obsolete or have not (yet) been entered and some zoos do not participate in ZIMS. Thus, actual counts may be higher. Therefore, we also checked the website "Zootierliste" (http://www.zootierliste.de/) for locating additional species holdings and institutions in Germany and Europe. However, it must be taken into account that this website also includes some private zoos and animal rescue facilities.

Results

Mating and oviposition

In Karlsruhe, the first breeding happened in 2008, two years after the first couple was obtained. Cologne Zoo received the first pair in July 2016 and four weeks later the first reproductive behavior could be observed. The first hatching event at Cologne Zoo occurred eight weeks after the receipt of the breeding pair; two months later the first successful hatching events took place.

Mating and oviposition was observed at Cologne Zoo in the morning, one to two hours after switching on the light. Mating started with the male and female moving side by side, with repeated quick laterally reversed bending of the tail region. Their fins were bent outwards and they were swimming with quick contracting movement. The foreplay could take up to one hour. Subsequently, they turned their bellies towards each other and the male offered his belly surface. The spawn was attached by the female with the ovipositor along the ventral side of

the male through repeated up and down motions (Fig. 3). Fertilization of eggs and attaching to the belly of the male took only a few minutes. The male carried the initially light orange eggs until hatching, which took place around eight days after oviposition. New egg depositions were observed to take place already one day after the last hatching event. Up to 99 eggs were counted per egg deposition, with eggs having a diameter of 1.5 mm including eggshell.

Development

In the beginning of the embryonic phase the eggs slowly turned from light orange to dark gray with a clear black embryonic structure inside. Those structures appeared about two days before hatching. Eight days after the egg deposition the larvae hatched at nighttime. We observed the

Fig. 3: Mating (left) and oviposition (right and lower left) of *Dunckerocampus pessuliferus* at the State Museum of Natural History Karlsruhe. Photos: J. Kirchhauser.

larvae to prefer the upper part of the tanks. In Cologne, it took one or two days for the larvae to hatch usually during the morning hours with either all hatching in one day or a few hatchlings at the first day and another 20-50 hatchlings during the second day. From the Karlsruhe spawn 40-70 juveniles hatched per egg deposition in one day. The freshly hatched larvae were transparent and had sizes of 4-5 mm. In comparison to the adults, their snout was shorter and they had an upwards bent body posture. Due to their initially lower head posture the larvae resembled the

Fig. 4: Egg development of *Dunckerocampus pessuliferus*: freshly attached eggs on 1st day (upper left), 2nd day (upper right), on 5th day, few days before hatching (lower left) and 8th day plus partially hatched larvae (lower right). Photos: J. Kirchhauser/M. Pfeiffer.

body structure of a seahorse. After three days, the first red pigmentation appeared on the caudal fin. In Cologne Zoo, the first pigmentation occurred seven days after hatching. Eight days after hatching, the larvae measured 11 mm and the caudal fins were completely red colored with a light pattern.

After two weeks in Karlsruhe and after ten days in Cologne Zoo, the juvenile *D. pessuliferus* had a size of 14 mm with a discernible banded color pattern, but with broader and irregular banding compared to the adult pattern. The yellow and white parts on the caudal fin were not yet noticeable.

During a period of three weeks, beginning three days after hatching, the juveniles frequently showed their fin directed upwards. Their body shape and color now resembled that of the adults in also having a white stripe above the caudal fin. At that stage they had reached a size of 25 mm. Throughout the next weeks the pigmentation developed further and they began to actively search for shelter, for example nearby plants. Another breeding attempt in Karlsruhe was implemented with *Artemia* as sole nourishment. After ten days, the juveniles had developed the distinct bending of the caudal fin. The first pigmentation started 12 days after hatching and was completed six days later. Moreover, there was a noticeable size deficit characterized by 10-13 mm smaller juveniles compared to copepod nourished fish. There was only a 7% survival rate with the nourishment exclusively with *Artemia*. In Karlsruhe, *D. pessuliferus* offspring had grown up to 9 cm after six months and first reproduction appeared after eight months. The juveniles in Cologne had a size of 4 cm after two months with the first reproduction attempts being observed after six months, with maximum sizes of 10.5-11 cm. After one year, they were grown to 13.5 cm. For details of the development see also Figs 4-7.

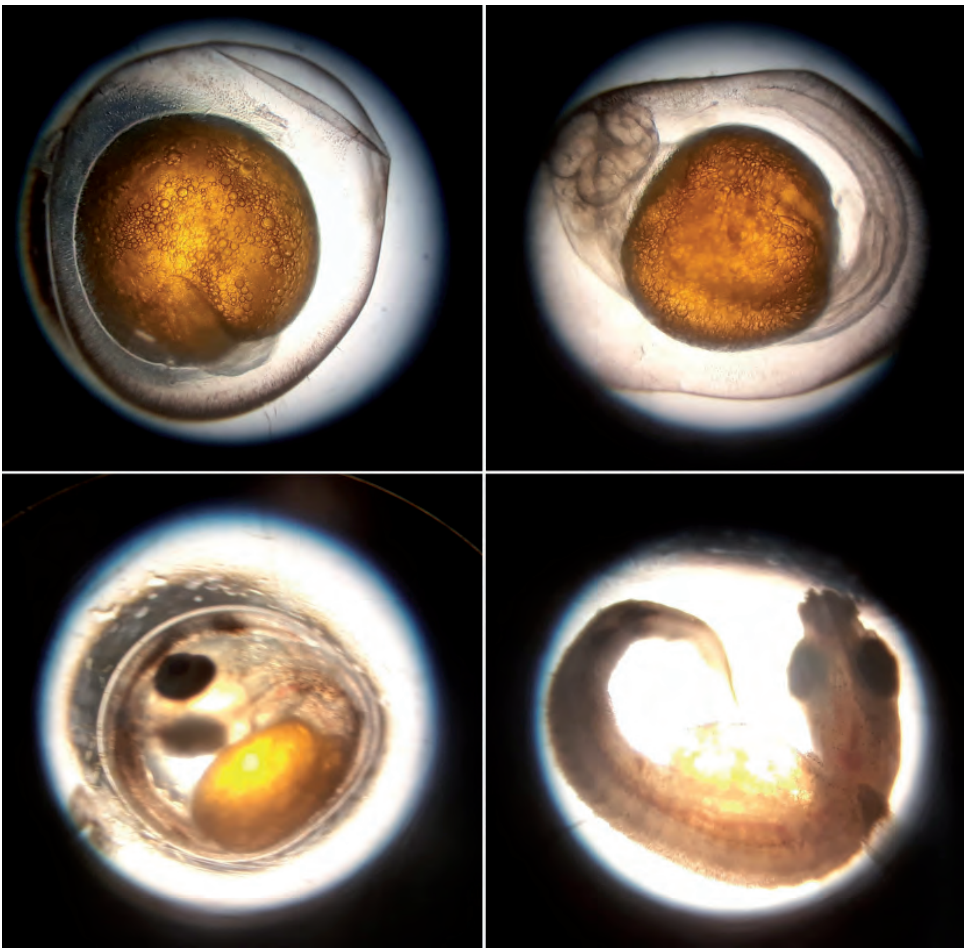

Fig. 5: Close-up development of one egg from *Dunckerocampus pessuliferus*: 2nd day (upper left), 3rd day (upper right), 6th day (lower left), and 7th day (premature hatching event, lower right). Photos: M. Pfeiffer.

Breeding success

In total, ten rearing events happened in Karlsruhe during the time of data acquisition. 15-35 juveniles matured per generation, the overall survival rate was 50%. In Cologne, so far eight rearings happened successfully with a hatching rate of 50%. The survival rate ranged from 6-47.3% in the first month (there were some losses due to a *Vibrio* infection) up to an average of 70% in the second month. The average survival rate in the first month was 25% subsequently followed by almost 100%. The strongest outage in Cologne was observed in the first five days. Until the 10th day only scattered death cases were observed (Fig. 8). In Karlsruhe, the highest outage occurred during the first three weeks. Thereafter the populations showed a stable development with only a few occasional deaths. We also observed that not all of the eggs showed to be fertilized and further eggs were detached from the male and got destroyed later on or did

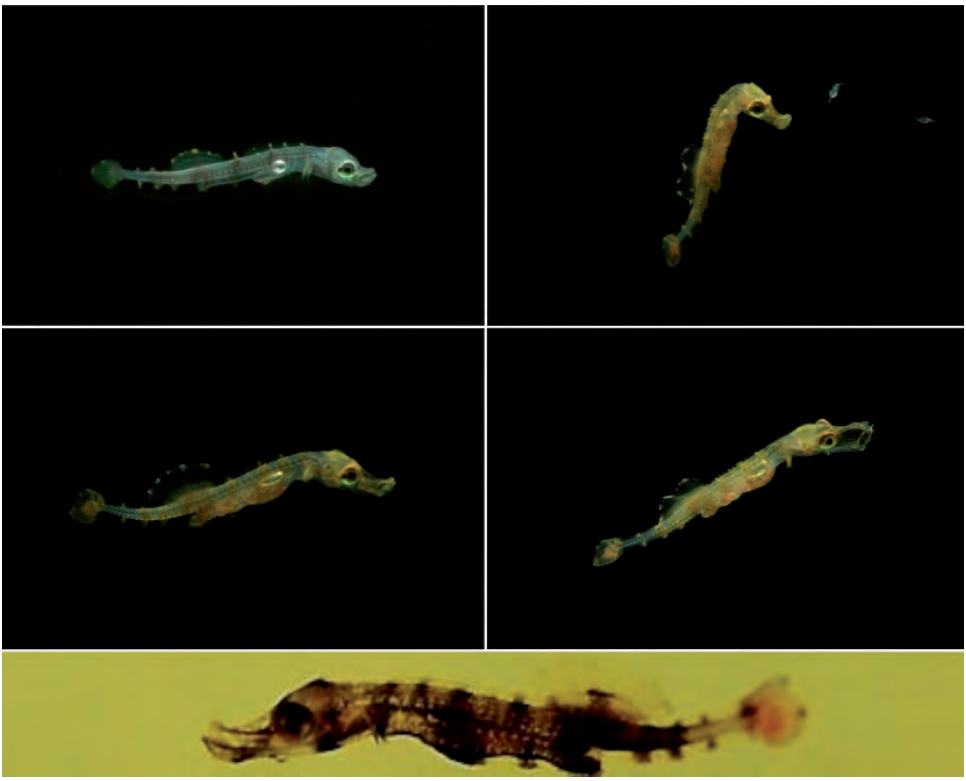

Fig. 6: Freshly hatched *Dunckerocampus pessuliferus* juveniles and few days old juvenile (bottom) with beginning coloration on the caudal fin. Photos: J. Kirchhauser/M. Pfeiffer.

not show further development. Larvae which hatched before the 8th day were not viable. After hatching they sunk and subsequently died. Parents then reacted with new and faster egg depositions. Usually, after 4 to 5 oviposition only normal breeding behavior could be observed.

We further observed that breeding proved to be unsuccessful when different stages of yellow-banded pipefish were held together in one aquarium (Karlsruhe). The joint keeping of different male yellow-banded pipefish after mating led to distinct rivalry. To the contrary, co-housing with seahorses was possible (Cologne Zoo).

The ten documented hatching events in Karlsruhe derived from the same breeding pair; the eight documented hatching events in Cologne likewise derived from one and the same breeding pair. At the time of the article writing only F1 offspring was available in both institutions, whereas during printing of this MS (November 2019) the fourth generation in Karlsruhe started breeding as well as the second generation in Cologne. In Karlsruhe, subsequent breeding pairs were formed by siblings or offspring from siblings, without any indication of inbreeding. Since July 2019, the individuals in Karlsruhe were paired with F1 offspring from Cologne.

ZIMS and “Zootierliste” analyses

In 2016, according to ZIMS, *Dunckerocampus pessuliferus* (still listed therein as *Doryrhamphus pessuliferus*) was kept by only six institutions worldwide with a total individual number

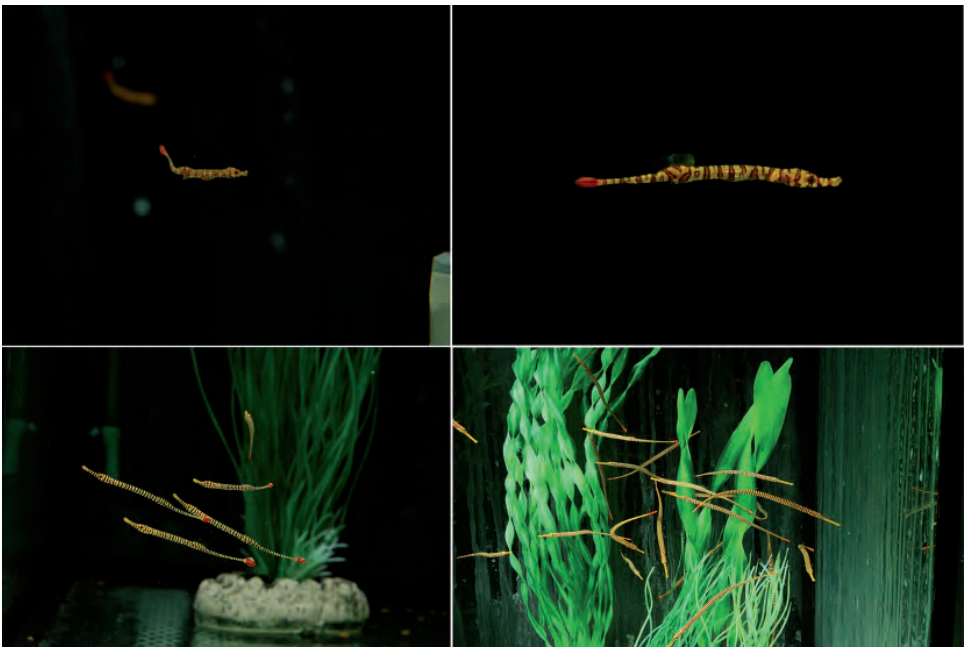

Fig. 7: Up to half year old juvenile *Dunckerocampus pessuliferus*: juvenile with fin directed upwards (upper left), juvenile shortly before reaching the complete color pattern (upper right), few weeks old juveniles (lower left), half year old juveniles (lower right). Photos: J. Kirchhauser.

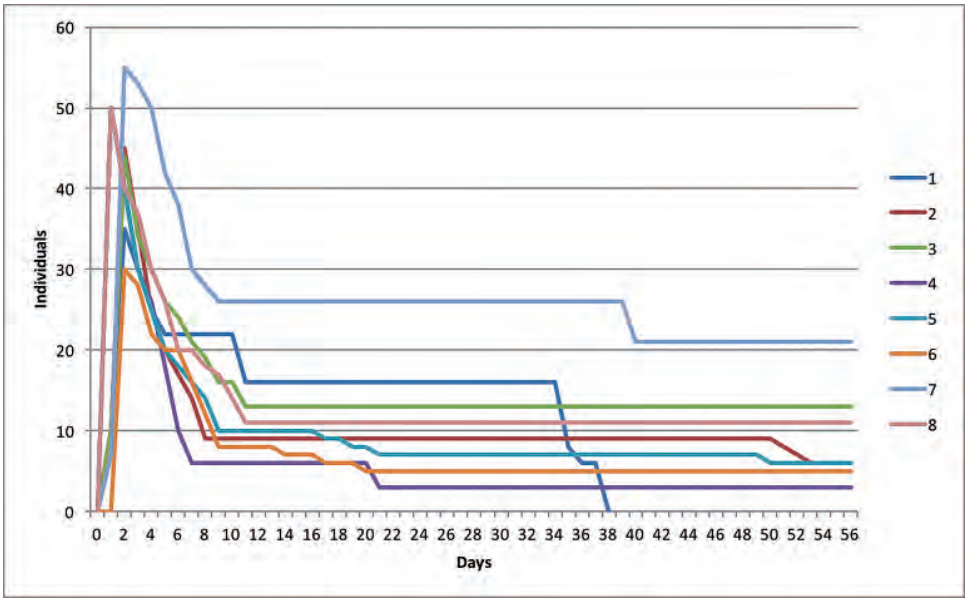

Fig. 8: Individual losses per *Dunckerocampus pessuliferus* hatch in Cologne Zoo starting with the first hatching event in October 2016 and the last recorded one in June 2017.

of only eight individuals: a single individual was held in each of the four institutions in North America (Birch Aquarium at Scripps Institute, Rosamond Gifford Zoo at Burnet Park, Tennessee Aquarium and Toledo Zoological Gardens) and two individuals in each of the two institutions in Europe (Cologne Zoo, Oceanario de Lisboa).

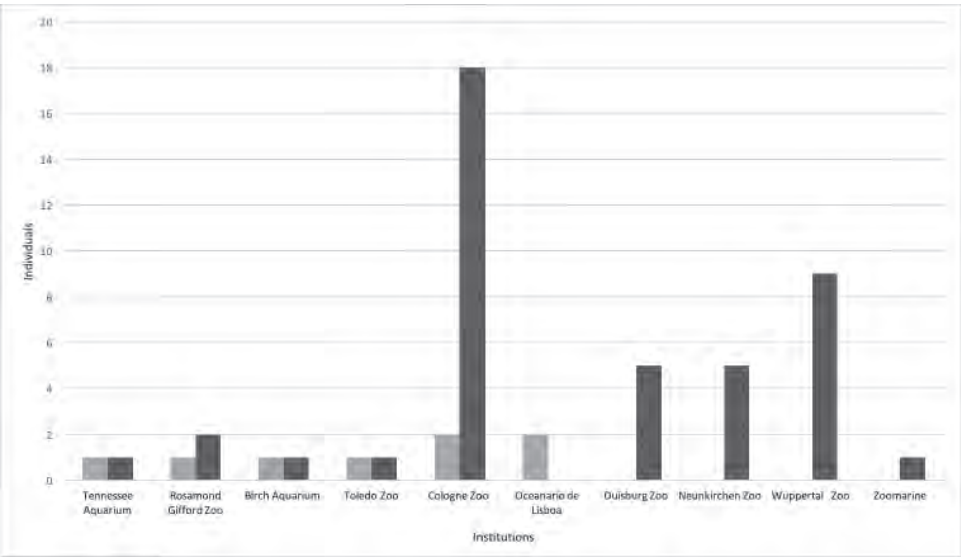

Fig. 9: Institutions worldwide keeping *Dunckerocampus pessuliferus*: data (including individual numbers) from October 2016 (light gray) versus May 2018 (dark gray) according to ZIMS.

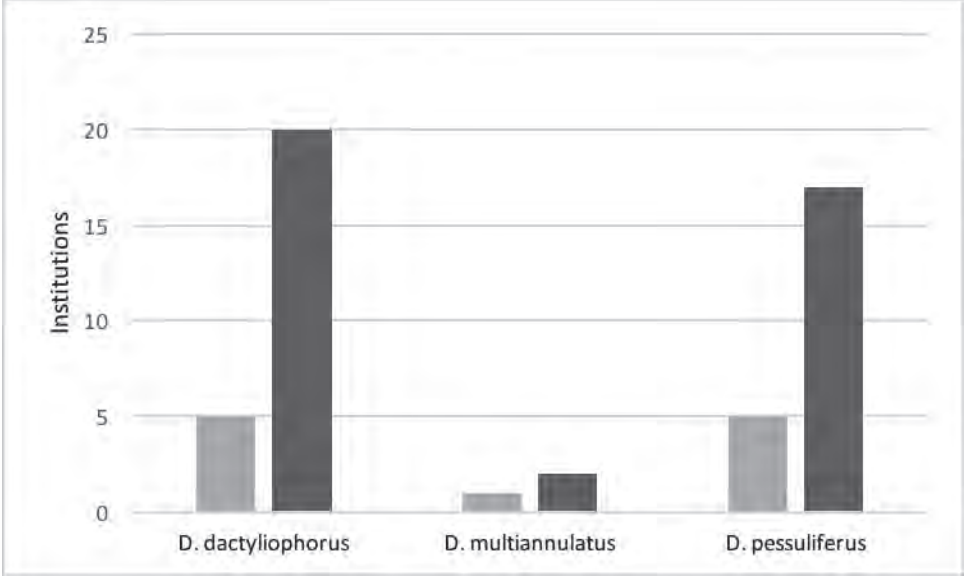

Fig. 10: Total number of institutions keeping *Dunckerocampus* in Europe (light gray: data according to ZIMS; dark gray: data from “Zootierliste”)

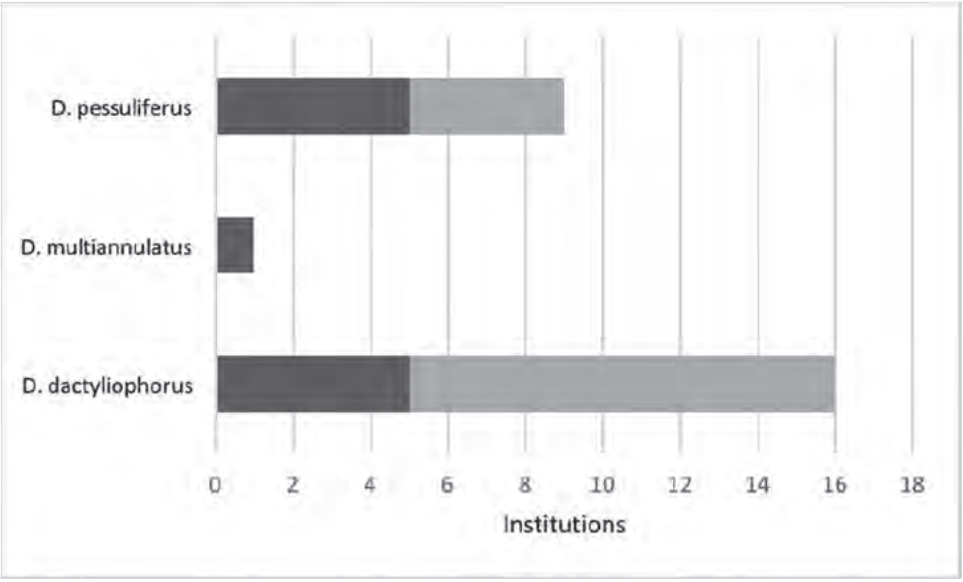

Fig. 11: Total number of institutions keeping *Dunckerocampus* (dark gray: Europe; light gray: globally) according to ZIMS.

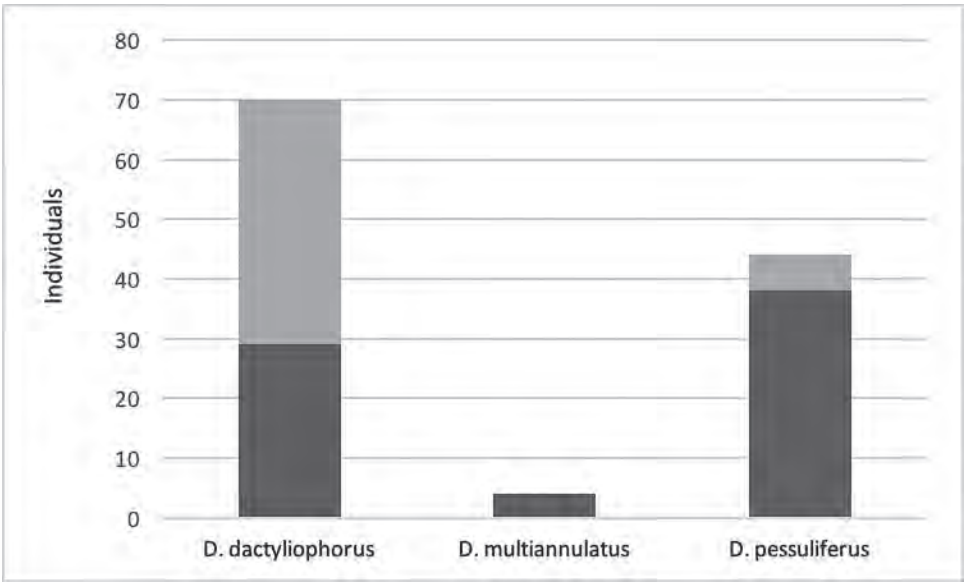

Fig. 12: Total individual numbers of *Dunckerocampus* kept in institutions (dark gray: Europe; light gray: globally) according to ZIMS.

In May 2018, the global number of institutions keeping *D. pessuliferus* had increased from six to nine according to ZIMS. Whereas holding institutions in the US stayed the same, in Europe Oceanario de Lisboa in Portugal resigned keeping *D. pessuliferus* whereas

Tab. 2: Overview of *Dunckerocampus* kept in zoos (May 2018) in a world-wide scale according to ZIMS (n = total number of individuals).

Species		n
D. dactyliophorus	In total 16 institutions from 3 regions	70
	Africa: 1 institution (males: 0; females: 0; other: 2)	
	Durban/Sea World uShaka	2
	Europe: 5 institutions (males: 0; females: 0; other: 29)	
	Beauval/Zoo Parc de Beauval	1
	Cologne/Cologne Zoo	21
	Lisboa/Oceanario de Lisboa	1
	St Peters/Leningrad Zoo	5
	Wuppertal/Wuppertal Zoo	1
	North America: 10 institutions (males: 4; females: 4; other: 31)	
	Quebec/Aquarium du Quebec	2
	Chattanoo/Tennessee Aquarium	4
	Epcot/Living Seas	2
	Moody/Aquarium & Rainforest at Moody Gardens	1
	Montemarin/Monte Marine Lab and Aquarium	1
	Niagara Falls/Aquarium of Niagara	8
	Denver/Landry's Downtown Aquarium	2
	Rio Grande/Albuquerque BioPark Zoo	11
	Steinhart/Steinhart Aquarium (CA Acad of Science)	6
	Tampa/Florida Aquarium	2
D. multiannulatus	In total 1 institution from 1 region	4
	Europe: 1 institution (males: 0; females: 0; other: 4)	
	Munich/Münchener Tierpark Hellabrunn	4
D. pessuliferus	In total 9 institutions from 2 regions	43
	Europe: 5 institutions (males: 2; females: 2; other: 34)	
	Duisburg/Duisburg Zoo	5
	Cologne/Cologne Zoo	18
	Neunkirch/Neunkircher Zoo	5
	Wuppertal/Wuppertal Zoo	9
	Zoomarine/Zoomarine - Mundo Aquatico S.A.	1
	North America: 4 institutions (males: 0; female: 0; other: 5)	
	Chattanoo/Tennessee Aquarium	1
	La Jolla/Birch Aquarium at Scripps Institute	1
	Syracuse/Rosamond Gifford Zoo at Burnet Park	2
	Toledo/Toledo Zoo	1

four new zoos stepped into the keeping of the species: Duisburg Zoo (n = 5 individuals), Neunkirchen Zoo (n = 5) and Wuppertal Zoo (n = 9) in Germany, as well as Zoomarine (n = 1) in Portugal. In the meantime, Cologne Zoo was able to increase the number of held yellow-banded pipefish from two to 18 individuals. In the US, Rosamond Gifford Zoo at Burnet Park was able to increase the number of animals from one to two individuals (Fig. 9). Therefore, in 2018 the total number of *D. pessuliferus* held in institutions around the

Tab. 3: Overview of *Dunckerocampus* kept in zoos (May 2018) in Europe according to "Zootierliste".

	Institutions	
	Germany	remaining Europe
D. dactyliophorus	11	9
D. multiannulatus	-	2
D. pessuliferus	10	7

world grew from initially eight to 43 individuals. The highest increase in individuals took place in Europe and here in particular in Germany (from 4 individuals to 37) mainly due to transfers of offspring from Cologne Zoo. However, gender in most cases is still unknown mostly due to recent hatching events.

Entries on the website "Zootierliste" from May 2018 showed a total of 17 European institutions holding *D. pessuliferus*: In total ten institutions in Germany and seven institutions in different European countries. Six listed institutions each from Germany and from other European countries were not included in ZIMS.

Further species of *Dunckerocampus* held in zoos based on ZIMS and "Zootierliste" data from May 2018 are shown in Tables 2 and 3 (see also Figs 10-12). Thus, of the currently seven recognized species 4 (57%) are presently not held in Zoos (*D. baldwini*, *D. boylei*, *D. chapmani*, and *D. naia*). However, it cannot be excluded that some zoos keep aforementioned species under different names or respective information has not yet been entered into ZIMS.

Discussion

Of the seven currently recognized *Dunckerocampus* species only three are represented within zoos (*D. dactyliophorus*, *D. multiannulatus*, *D. pessuliferus*), mostly in Europe and North America. There is only scarce information published about husbandry and breeding of *Dunckerocampus* (Lange, 1989; Nikolay et al., 2011; Krause, 2012). It thus was the aim of this publication to provide a guideline for increased *Dunckerocampus* breeding, based on *D. pessuliferus* as husbandry analogue, adapted from experiences with the husbandry and successful and repeated reproduction both at the State Museum of Natural History Karlsruhe and in the Aquarium of the Cologne Zoo, Germany.

Based on our experiences with the breeding of *D. pessuliferus* we found that continuous and adequate nourishment in sufficient densities and increased quantities with growing larval size was among the most important parameters for successful keeping and breeding. Also, nutrition of larvae with diverse food supply is recommended as feeding with *Artemia* solely revealed to be insufficient. However, feeding with *Brachionus* was discontinued at the State Museum of Natural History Karlsruhe, as pipefish and also seahorses scarcely reacted to the sliding movements of the rotifers. There have been different studies on other pipefish species which revealed copepods to be the main prey, amounting to 83.5%. Due to the small mouth opening and the particular feeding mechanism prey cannot exceed a particular size (Teixeira & Vieira, 1995; Garcia et al., 2005). Larger growing prey such as *Artemia* larvae might be inappropriate or more difficult and cost expensive to overwhelm especially for juvenile pipefish (Gerking, 1994; Garcia et al., 2005).

In general, the breeding of marine fishes in zoos is still comparatively low and almost all of the marine fishes in the trade are wild-caught (Andrews, 2006). One of the reasons for the

limited captive breeding in zoos is still the lack of basic rearing knowledge for many marine species (Ajith Kumar et al., 2015). Compared to freshwater species which mostly derive from captive breeding, 90 to 99% of marine fishes traded are from wild origin (Oliver, 2003; Tissot & Hallacher, 2003; Calado, 2006). Furthermore, they are mostly harvested with techniques that have a high impact on the marine ecosystem such as the use of cyanide. Due to the increasing effects of climate change including rising sea surface temperatures and ocean acidification, pollution and overfishing, the marine biodiversity is under threat (Moore, 2008; Teuten et al., 2009; Thompson et al., 2009; Ryan et al., 2009; Tanaka et al., 2013). Because of the rapid deterioration of marine ecosystems, increased breeding as well as conservation breeding can significantly contribute to the maintenance of marine organisms.

D. pessuliferus is protected in the Australian portion of its range by the Environment Protection and Biodiversity Conservation Act (1999). However, there are no species-specific conservation actions in place. As breeding and provision of sufficient offspring to other zoos is feasible, as we were able to demonstrate herein, sustainable aquaristics is approachable regarding this species.

Our analyses showed that both collections keeping *D. pessuliferus* and the number of individuals kept distinctly increased in the past two years. Meanwhile, in Germany, the State Museum of Natural History Karlsruhe is able to provide around 50 young every year and also Cologne Zoo, that later initiated breeding, was already able to provide more than 20 young to supply four zoos in Germany. Two of the latter institutions subsequently initiated successful breeding of *D. pessuliferus* in Germany. And our experiences with the keeping and breeding of *D. pessuliferus* are also generally applicable to the management of other *Dunckerocampus* species. *D. dactyliophorus* was also successfully bred both at the Cologne Zoo and the State Museum of Natural History Karlsruhe applying the same methods described herein for *D. pessuliferus*.

Recently there has been a rethinking of ocean conservation in zoos (Barongi et al., 2015). There is an increasing number of aquariums which have implemented research programs and contribute to or have built up conservation programs for specific marine ecological systems or fish species. Even though such efforts are in place, fish are still underrepresented in terms of re-establishing projects of wild populations (Gilbert et al., 2017). In addition, only about half of the known extant fish species have been assessed for The IUCN Red List of Threatened Species (Pollom, 2016).

With targeted species selection and more investment in breeding efforts, investigation and communication there is a chance to enhance from public display and education purposes towards buildup of sustainable captive colonies and even conservation breeding/assurance populations under human care. Increase in knowledge of husbandry and breeding as well as of the general biology of species further can assist wildlife biologists and conservationists in the management of the species and also can be critical for the development of new culture methods or transferring culture systems to other species (e.g. Dhert et al., 1997). Only recently, da Silva et al. (2019) highlighted both the great value of aquarium and zoo collections for addressing the aquatic biodiversity crisis as well as the importance that they maintain comprehensive, standardized globally shared taxonomic data.

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Zusammenfassung

Als Leitfaden für eine optimierte *Dunckerocampus*-Nachzucht, basierend auf *D. pessuliferus* als sogenannter „Husbandry analogue“ Art, stellen wir die Haltung und Vermehrung in Menschenhand sowie die Larvalentwicklung dieser Art im Staatlichen Museum für Naturkunde Karlsruhe, Deutschland, und im Aquarium des Kölner Zoos, Deutschland, gegenüber. Beobachtete Paarungen, bei der die Eier an das Männchen geheftet wurden, dauerten bis zu einer Stunde. Die Jungtiere schlüpften nach acht Tagen mit Größen von 4-5 mm. Die Erwachsenenfärbung entwickelte sich nach drei Wochen und nach sechs Monaten waren die Sulu-Seenadeln mit einer Gesamtlänge von 10,5-11 cm geschlechtsreif. Wir geben Überlebensraten an und machen Empfehlungen für **e**ine optimale Fütterung. Zusätzlich führten wir eine ZIMS-Datenbankanalyse (Zoological Information Management System) (Oktober 2016 und Mai 2018) durch, die auf einen Anstieg der Haltungen von *D. pessuliferus* verwies. Derzeit halten neun Institutionen weltweit (fünf davon in Europa) diese Art (mit insgesamt 43 Individuen). Da nicht alle Zoos ihre Bestandszahlen in ZIMS eingeben, überprüften wir ebenfalls die Webseite „Zootierliste“ (http://www.zootierliste.de/), um zusätzliche Arthaltungen in Deutschland und anderen Ländern in Europa zu finden, die allerdings auch private Zoos und Auffangstationen beinhalten. Eintragungen auf der Webseite „Zootierliste“ vom Mai 2018 zeigten insgesamt 17 Einrichtungen in verschiedenen europäischen Ländern, davon zehn Institutionen in Deutschland und sieben in anderen Ländern Europas. Jeweils sechs der aufgeführten Einrichtungen aus Deutschland und anderen europäischen Ländern waren nicht in ZIMS enthalten. Laut ZIMS wurden nur zwei weitere Arten der sieben derzeit anerkannten *Dunckerocampus*-Arten weltweit in Zoos gehalten: *D. dactyliophorus* verteilt sich mit 70 Individuen auf 16 Zoos in Nordamerika (10), Europa (5) und Afrika (1) und *D. multiannulatus* ist mit vier Individuen in nur einer Einrichtung in Europa vertreten. Die Wichtigkeit von Nachzuchtbemühungen von noch nicht oder bislang kaum gezüchteten Meerwasserfischarten sowie verbessertem Austausch von Kenntnissen und verfügbaren Beständen zwischen den Einrichtungen, einschließlich Veröffentlichungen über Haltungsmanagement und Nachzuchterfolgen für eine nachhaltigere Aquaristik, wird betont.

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