

First report of hybridization between *Mauremys leprosa* and *Mauremys sinensis* highlights the risk of exotic *Mauremys* spp. pet trade

Vicente Sancho^{1,*}, Ignacio Lacomba², José V. Bataller³, Joana Veríssimo⁴, Guillermo Velo-Antón^{4,*}

¹ Càdec, Taller de Gestió Ambiental, S.L. València, Spain.

² Àrea de Medi Ambient i Canvi Climàtic. Servei d'Energies Renovables i Canvi Climàtic. Ajuntament de València, Spain.

³ Centre for the Conservation of Freshwater Species of the Valencia Region. Generalitat Valenciana. València, Spain.

⁴ CIBIO-InBIO, Universidade do Porto, Campus de Vairão, Rua Padre Armando Quintas 7. 4485-661 Vairão, Portugal.

*Correspondence: E-mail: cadecambiental@gmail.com (Vicente Sancho); guillermo.velo@gmail.com (Guillermo Velo-Antón)

Received: 30 April 2020; returned for review: 14 June 2020; accepted 29 June 2020.

The global exponential growth in the number of exotic turtle species exploited in the pet trade market facilitates hybridization events between distantly related species. The 1997 EU trade ban on red-eared slider turtles (*Trachemys scripta elegans*), followed by the Spanish ban on all *T. scripta* subspecies in 2011, resulted in the importation of other chelonians (e.g. *Graptemys* spp., *Pseudemys* spp., *Mauremys* spp.), mainly from America and Asia to Spain. The importation of the Chinese stripe-necked pond turtle, *Mauremys sinensis*, via the pet trade market resulted in its release into natural environments across Europe, including the Iberian Peninsula where it co-occurs with the Western Mediterranean pond turtle, *Mauremys leprosa*. We maintained three *M. leprosa* females and two *M. sinensis* males in captivity, and analysed the obtained offspring (two hatchlings) with mitochondrial (cytochrome *b*) and nuclear (R35) genetic markers. Both morphological (i.e. with intermediate morphological characters) and genetic (heterozygous hatchlings) results confirmed the hybridization between these two species and raise concern about the negative effects of acclimated *Mauremys sinensis* across the *Mauremys leprosa* range.

Key words: captivity; conservation; hybridization; *Mauremys leprosa*; *Mauremys sinensis*; Spain.

The family Geoemydidae is the largest family of turtles, comprising 19 genera and 69 aquatic or semi-aquatic species (VAN DIJK *et al.*, 2014), distributed throughout Europe, North Africa, the Middle East to China, southern Russia, Indonesia and the Philippines, with only one genus occupying the American continent, from Mexico

to Brazil (IVERSON, 1992; LE & McCORD, 2008). A large number of hybridization events have been reported within this family (see BUSKIRK *et al.*, 2005), even between phylogenetically distant genera such as *Cuora-Mauremys*, *Cuora-Geoemyda*, *Cyclemys-Mauremys* or *Sacalia-Mauremys* (e.g. OTANI, 1995; SCHILDE *et al.*, 2004; BUSKIRK *et*

al., 2005; ZHOU *et al.*, 2015), which has also led to incorrect descriptions of new species (PARHAM *et al.*, 2001; WINK *et al.*, 2001, SPINKS *et al.*, 2004, STUART & PARHAM, 2007). Within the genus *Mauremys*, cases of hybridization were reported in both captive conditions (e.g. *M. leprosa* and *M. reevesii*, NICKL, 2015), and natural populations (e.g. Asian *M. sinensis* and *M. reevesii*, XIA *et al.*, 2011; FONG & CHEN, 2010; and the European *M. rivulata* and *M. caspica*, FRITZ *et al.*, 2008).

The global exponential growth in the number of exotic turtle species increases the release of exotic species by pet-owners into native ecosystems, facilitating hybridization events with wild relatives, and potentially become invasive. One of the most commercially important turtle species is the red-eared slider, *Trachemys scripta elegans*, which became one of the 100 most harmful invasive species in the world (LOWE *et al.*, 2000). In 1997 it was banned from selling in the European pet trade market (EUROPEAN COMMISSION, 1997), as well as all subspecies of *T. scripta* in Spain since 2011 (MINISTERIO DE MEDIO AMBIENTE, MEDIO RURAL Y MARINO, 2011). After this ban, pet stores introduced other chelonians, both from America (e.g. *Graptemys* spp. and *Pseudemys* spp.), and Asia (e.g. *M. reevesii* and *M. sinensis*) to the pet trade market. According to a survey in 684 of the 1499 official turtle farms in China, the production of Asian Geoemydidae has increased significantly in the last years, with ca. 1.8 million *M. sinensis* available for sale every year (HAITAO *et al.*, 2008).

As a direct consequence of the importation of non-banned exotic species, a growing number of individuals of the Chinese

stripe-necked pond turtle, *Mauremys sinensis*, were found across Europe (e.g. Italy, PANZERI *et al.*, 2014; Slovakia, JABLONSKI *et al.*, 2018), and the Iberian Peninsula (CAMPUS-SUCH *et al.*, 2016; SILVESTRE *et al.*, 2019;), where it co-occurs with wild populations of the Mediterranean Stripe-necked Terrapin (or Western Mediterranean pond turtle) *Mauremys leprosa*. While *M. sinensis* is native to China, Taiwan and Vietnam, *M. leprosa* is widely distributed in the Iberian Peninsula (with a few scattered populations in the southern France) and in the Maghreb (VERÍSSIMO *et al.*, 2016). Here, we aim to evaluate the potential hybridization between these two species by maintaining individuals in captive conditions and analyzing the obtained offspring with mitochondrial and nuclear markers.

We collected two males of *M. sinensis* (157 & 192 mm carapace length, C.L.) from Burriana marsh (39°53'29" N, 0°2'37" W) and three females of *M. leprosa* (224, 226 & 240 mm C.L.) from Castellón marsh (39°59'11" N, 0°0'26" E) in eastern Spain. We kept them in the facilities of the Centre for the Conservation of Freshwater Species of the Valencia Region (CCEDCV) in a 2x2 m outdoor pool with 2/3 of its surface filled with water (maximum depth 35 cm) and 1/3 of loose soil to facilitate egg laying.

We fed them with semi floating Trout feed pellets (Skretting© t-6 Optiline 3P sf) until oviposition (from July 19th 2013 to October 26th 2015).

During the first breeding season, we obtained two clutches of 11 and three eggs from two *M. leprosa* females, which were incubated in moistened vermiculite (1 part of water per 1 part of vermiculite) at 28°C (ExoTerra© PT2499). After four weeks we



Figure 1: Photo of a six-month-old hybrid between *Mauremys leprosa* and *M. sinensis*. Head and neck is typical of *M. sinensis*, with greenish and black stripes on a pale-yellow background, without the orange tones typical of *M. leprosa* juveniles (Photo: V. Sancho).

verified that all eggs were infertile (i.e. embryos were not present upon opening them). In the second breeding season we observed two other clutches. Four eggs of the first clutch were maintained under the same conditions mentioned above, during seven weeks, after which only one egg hatched. The second female deposited nine eggs that were kept outdoors in the nest, with just one hatching after 52 days.

We collected buccal swabs from the two *M. sinensis* males, one of the successfully breeding *M. leprosa* females, and the two putative *M. sinensis-leprosa* hatchlings, and preserved them in ethanol for molecular analysis. We targeted DNA fragments of the cytochrome *b* mitochondrial gene (*cytb*; ca. ~1000 base pairs) and one nuclear intron (*R35*; ca. ~1000 base pairs), following a recent study unveiling the biogeographic history of *M. leprosa* (VERÍSSIMO *et al.*, 2016). For *cytb* we used the primers mt-aneu (LENK & WINK, 1997) and H-15909 (LENK *et al.*, 1999), and primers R35 Ex1 and R35 Ex2 (FUJITA *et al.*, 2004) for *R35* (see VERÍSSIMO *et al.*, 2016 for further information on PCR and sequencing conditions for each marker). Sequences were verified and aligned by eye using Geneious R11.1.4 (<http://www.geneious.com/>). Due to an

indel presence and heterozygous positions in the *R35* intron, sequences were phased in DnaSP v5.10 (LIBRADO & ROZAS, 2009) to reconstruct haplotypes. *Cytb* and *R35* sequences were blast against our own databases and BLASTn (<https://blast.ncbi.nlm.nih.gov/>) to confirm species assignment of the specimens used. This includes 68 and 28 *cytb* sequences (unique haplotypes) and 14 (unique haplotypes) and 19 *R35* sequences for *M. leprosa* and *M. sinensis*, respectively.

Heads and necks of the two hatchlings were typical of *M. sinensis* with greenish and black stripes on a pale-yellow background, without the orange tones typical of *M. leprosa* juveniles (Fig. 1). The carapace showed a well marked central keel, while the side keels were reduced. The colour was uniformly brown, without the orange tones typical of *M. sinensis*. The plastron showed an intermediate pattern between *M. sinensis* and *M. leprosa*, with the characteristic dark quadrangular blotches of *M. sinensis*, with a brownish background, although they both lack the second blotch on the bridge side of pectoral and abdominal scutes (Figs. 1 and 2).

The obtained *cytb* sequences for the female and the two males were identified

A



B



Figure 2: (A) Dorsal view comparing the carapace of *M. sinensis* (left), hybrid (center) and *M. leprosa* (right). (B) Ventral view comparing the plastron of *M. sinensis* (left), hybrid (center) and *M. leprosa* (right). The two four year-old hybrids shown brownish carapace without orange tones, and plastron with quadrangular blotches, but lacking the second blotch on pectoral and abdominal scutes. Photos: J. M. López.

as *M. leprosa* and *M. sinensis*, respectively. However, all the *cytb* sequences differ in a few positions from the sequences retrieved from GenBank, and thus were deposited with the following codes: MT629907-MT629911. The two *M. sinensis* males were

differentiated in one mutation.

The *R35* nuclear sequences were trimmed to ca. 368 bp due to the impossibility of unambiguous base calling when *M. sinensis* and *M. leprosa* haplotypes overlapped after one detected intron, and were

SHORT NOTES

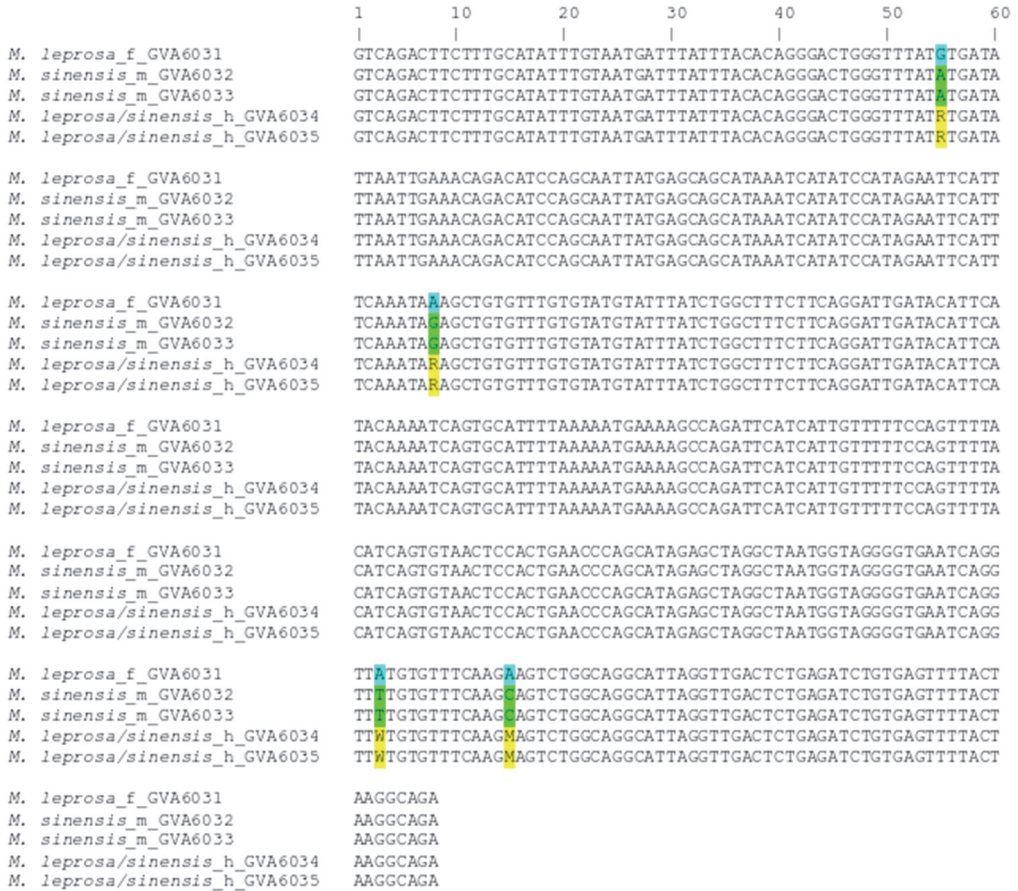


Figure 3: R35 sequence alignment for *M. leprosa*, *M. sinensis* and their hybrids, highlighting with different colours the position of the four diagnostic nucleotide bases. Female (f), males (m), hybrids (h), and voucher codes (GVA) are shown in the specimens' ID code.

confirmed as *M. leprosa* (GenBank Acc. No.: KX374284.1) and *M. sinensis* (GenBank Acc. No.: GQ259470.1). There are four diagnostic positions between *M. leprosa* and *M. sinensis* (Fig. 3).

The two hatchlings showed *M. leprosa* mitochondrial haplotype (as mitochondrial DNA is inherited in the maternal line) and heterozygous positions in each of the four variable positions observed in R35 sequences (Fig. 3).

Our results unambiguously confirm F1 hybrids between *M. leprosa* and *M.*

sinensis. Despite these hybrids were obtained in captivity, and the low levels of fertile eggs during the experiment, we confirm the hybridization between the exotic *Mauremys sinensis* and the native *Mauremys leprosa* and highlight the particular risk of *Mauremys* spp. pet trade in the Iberian Peninsula and northern Maghreb, which would have important implications to the long-term survival of the Mediterranean Stripe-necked Terrapin. Indeed, reproduction of *M. sinensis* was detected in semi-natural popula-

tions of the Iberian Peninsula (SILVESTRE *et al.*, 2019), which confirms the acclimatization of this Asian turtle to the Mediterranean environment typical of *M. leprosa*. It remains unknown if *M. sinensis/leprosa* F1 are fertile, or the effects on population growth and survival of the hybrids.

As *M. sinensis* is increasingly present in pet shops and owners often release them in the wild, the conservation of *M. leprosa* populations may be compromised if the sale of these exotic taxa continues.

Acknowledgement

This project was funded by the LIFE + Trachemys (LIFE+09 NAT/ES/000529) Project, co-financed by the European Commission and the Generalitat Valenciana, and by Instituto de Estudios Ceutíes (2012). Pilar Risueño, Jesús Hernández and José Velázquez, from the CCEDCV helped in the maintenance of specimens. José María López (SOHEVA) provided photographs in Fig. 2. GVA was supported by FCT (IF/01425/2014).

REFERENCES

- CAMPOS-SUCH, D.; MIÑARRO, M., & VALLS, L. (2016). Localización de un ejemplar asilvestrado de *Mauremys sinensis* en la Comunidad Valenciana. *Boletín de la Asociación Herpetológica Española* 27: 97-99.
- BUSKIRK, J.R.; PARHAM, J. F. & FELDMAN, C.R. (2005). On the hybridization between two distantly related Asian turtles (Testudines: *Sacalia · Mauremys*). *Salamandra* 41: 21-26.
- EUROPEAN COMMISSION (1997). Commission Regulation (EC) No 2551/97 of 15 December 1997 suspending the introduction into the Community of specimens of certain species of wild fauna and flora. Official Journal L 349, 19/12/1997, P. 0004-0017.
- FONG, J.J. & CHEN, T. H. (2010). DNA evidence for the hybridization of wild turtles in Taiwan: possible genetic pollution from trade animals. *Conservation Genetics* 11: 2061-2066.
- FRITZ, U.; AYAZ, D.; BUSCHBOM, J.; KAMI, H.G.; MAZANAeva, L.F.; ALOUFI, A.A.; AUER, M.; RIFAL, L.; ILIC, T.S. & HUNSDORFER, A.K. (2008). Go east: phylogeographies of *Mauremys caspica* and *M. rivulata*-discordance of morphology, mitochondrial and nuclear genomic markers and rare hybridization. *Journal of Evolutionary Biology* 21: 527-540.
- FUJITA, M.K.; ENGSTROM, T.N.; STARKEY, D.E. & SHAFFER, H.B. (2004). Turtle phylogeny: insights from a novel nuclear intron. *Molecular Phylogenetics and Evolution*, 31: 1031-1040.
- HAITAO, S.; PARHAM, J.F.; ZHIYONG, F.; MEILING, H. & FENG, Y. (2008). Evidence for the massive scale of turtle farming in China. *Oryx*, 42: 147-150.
- IVERSON, J.B. (1992). *A Revised Checklist with Distribution Maps of the Turtles of the World*. Privately printed, Richmond, VA, USA.
- JABLONSKI, D.; GRUL'A, D. & CHRISTOPHORYOV, J. (2018). First record of *Mauremys sinensis* (Gray, 1834) and its natural overwintering in Central Europe. *Herpetology Notes* 11: 949-951.
- LE, M. & MCCORD, W. P. (2008). Phylogenetic relationships and biogeographical history of the genus *Rhinoclemmys* Fitzinger, 1835 and the monophyly of the turtle family Geomydidae (Testudines: Testudinoidea). *Zoological Journal of the Linnean Society* 153: 751-767.
- LENK, P. & WINK, M. (1997). A RNA/RNA heteroduplex cleavage analysis to detect rare mutations in populations. *Molecular Ecology* 6: 687-690.
- LENK, P.; FRITZ, U.; JOGER, U. & WINK, M. (1999). Mitochondrial phylogeography of the European pond turtle, *Emys orbicularis* (Linnaeus 1758). *Molecular Ecology* 8: 1911-1922.
- LIBRADO, P. & ROZAS, J. (2009). DnaSP v5: a software for comprehensive analysis of DNA polymorphism data. *Bioinformatics* 25): 1451-

- 1452.
- LOWE, S.; BROWNE, M.; BOUDJELAS, S. & DE POORTER, M. (2000). *100 of the World's Worst Invasive Alien Species A selection from the Global Invasive Species Database*. Invasive Species Specialist Group (ISSG), Auckland, New Zealand.
- MINISTERIO DE MEDIO AMBIENTE, Y MEDIO RURAL Y MARINO (2011). Real Decreto 1628/2011, de 14 de noviembre, por el que se regula el listado y catálogo español de especies exóticas invasoras. B.O.E., 298 de 12.12.2011: 132711-132735.
- NICKL, S. (2015). Kann denn Liebe Sünde sein? Eine Randnotiz zu Hybriden aus *Mauremys leprosa* und *Mauremys reevesii*. *Marginata* 44: 60-64.
- OTANI, T. (1995). Possible hybrids between *Geoemyda japonica* and *Cuora flavomarginata* found on Okinawajima Island, Ryukyu Archipelago. *Akamata* 11: 25-26.
- PANZERI, M.; MORI, E.; MAZZA, G. & MENCHETTI, M. (2014). Records of introduced stripe-necked terrapins (*Mauremys* species) in Italy. *Acta Herpetologica* 9: 227-230.
- PARHAM, J.F.; SIMISON, W.B.; KOZAK, K.H.; FELDMAN, C.R. & SHI H. (2001). New Chinese turtles: Endangered or invalid? A reassessment of two species using mitochondrial DNA, allozyme electrophoresis, and known locality specimens. *Animal Conservation* 4: 357-367.
- SCHILDE, M.; BARTH, D. & U. FRITZ (2004). An *Ocadia sinensis* × *Cyclemys shanensis* hybrid (Testudines: Bataguridae). *Asiatic Herpetological Research*, 10: 120-125.
- SILVESTRE, A.M.; SOLER, J. & CANO, J.M. (2019). Adaptación y reproducción de *Mauremys sinensis* a las condiciones naturales del nordeste de la península ibérica. *Boletín de la Asociación Herpetológica Española* 30: 75-78.
- SPINKS, P. Q.; SHAFFER, H.B.; IVERSON, J.B. & McCORD W. P. (2004). Phylogenetic hypotheses for the turtle family Geoemydidae. *Molecular Phylogenetics & Evolution* 32: 164-182.
- STUART, B.L. & PARHAM J.F. (2007). Recent hybrid origin of three rare Chinese turtles. *Conservation Genetics* 8: 169-175.
- VAN DIJK, P.P.; IVERSON, J.B.; RHODIN, A.G.J.; SHAFFER, H.B. & BOUR, R. (2014). Turtles of the world, 7th edition: Annotated checklist of taxonomy, synonymy, distribution with maps, and conservation status, In A.G.J. Rhodin, P.C.H. Pritchard, P.P. van Dijk, R.A. Saumure, K.A. Buhlmann, J.B. Iverson & R.A. Mittermeier (eds.) *Conservation Biology of Freshwater Turtles and Tortoises: A Compilation Project of the IUCN/SSC Tortoise and Freshwater Turtle Specialist Group*. Series: Chelonian Research Monographs, vol. 5. Chelonian Research Foundation, Lunenburg, Massachusetts, USA, pp. 329-479.
- VERÍSSIMO, J.; ZNARI, M.; STUCKAS, H.; FRITZ, U.; PEREIRA, P.; TEIXEIRA, J.; ARCULEO, M.; MARRONE, F.; NAIMI, M.; KEHLMAYER, C. & VELOANTÓN, G. (2016). Pleistocene diversification in Morocco and recent demographic expansion in the Mediterranean pond turtle *Mauremys leprosa*. *Biological Journal of the Linnean Society* 119: 943-959.
- WINK, M., GUICKING, D. & FRITZ, U. (2001). Molecular evidence for hybrid origin of *Mauremys iversoni* Pritchard et McCord, 1991, and *Mauremys pritchardi* McCord, 1997 (Reptilia: Testudines: Bataguridae). *Zoologische Abhandlungen* 51: 41-49.
- XIA, X.; WANG, L.; NIE, L.; HUANG, Z.; JIANG, Y.; JING, W. & LIU, L. (2011). Interspecific hybridization between *Mauremys reevesii* and *Mauremys sinensis*: Evidence from morphology and DNA sequence data. *African Journal of Biotechnology* 10: 6716-6724.
- ZHOU, H.; JIANG, Y.; NIE, L.; YIN, H.; LI, H.; DONG, X.; ZHAO, F.; PU, Y.; HUANG, Z.; SONG, J. & Sun, E. (2015). The historical speciation of *Mauremys* Sensu Lato: ancestral area reconstruction and interspecific gene flow level assessment provide new insights. *PloS One* 10: E0144711.