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Editorial

Advances in the Biology and Conservation of Turtles

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The approximately 356 species of testudines (turtles) are remarkable for their blend of phylogenetic conservatism and diversity. Turtles and their shells evolved over 220 million years ago [1,2], and the turtle shell has remained diagnostic to clade Testudinata [3]. The combination of dermal and skeletal bones making up the shells of modern turtles has been modified through natural selection in many ways, from the heavily armored boxes of some land turtles to the tough, highly streamlined versions of some water turtles. Hinges, even double hinges in some species, have evolved repeatedly, making the shell even more impregnable to predators and desiccation. As a result, turtles live in habitats as diverse as temperate and tropical forests, rivers and other bodies of water of all sizes, all tropical and subtropical deserts, oceanic islands, and even oceans in the Arctic Circle. The shell is a costly investment, adding bulk and mass and constraining locomotion, and is thus associated with delayed maturity, but is also coupled with extreme longevity, making the investment cost-effective.

Currently, more than half of turtle species are threatened with extinction, making them among the most highly endangered taxa [4]. There are multiple reasons for this predicament, but all are anthropogenic—primarily habitat loss and collection for food, traditional medicines, and the international pet trade. These are complex problems that can be addressed, but political opposition is formidable. For example, despite high demand for turtle parts as ingredients for traditional pharmaceuticals, there is no evidence they have any actual medicinal effect. Therefore, demand should disappear with more critical evaluation of these traditional ingredients and their replacement with pharmaceuticals that actually work.

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In contrast to the dire conservation situation of many turtle species, the red-eared slider (*Trachemys scripta*) is included in the list of the world's 100 most invasive species [5]. *T. scripta* is a typical turtle, with the usual delayed maturation and low juvenile survivorship. However, this species happens to be easy and cheap to mass produce in the United States, which ships hatchlings for the pet trade all over the world. Adult sliders tend to be poor pets, and are commonly released into local waterways, where their broad habitat and dietary demands serve them well as colonists. No other turtle species has been anywhere near as successful, although some (e.g., snapping turtles, *Chelydra serpentina*) have also been successfully introduced in many places well outside their native ranges.

The fifteen papers in this SI highlight novel research projects involving turtles, including understudied species, interspecific comparisons, and new and neglected techniques. Six of the papers are detailed evaluations of field techniques, which are especially important in monitoring rare and endangered species. Making turtle censuses easier yet accurate can facilitate conservation. Two of the papers [6,7] focus on interesting new techniques (visual head counts and surveys of parasitic trematodes) for surveying diamondback terrapins (*Malaclemys terrapin*), a declining species listed as Vulnerable by the IUCN [8]. Like many turtles, terrapin population trends are difficult to measure with precision or accuracy, and these new techniques offer easier methods, which are even usable by citizen scientists. In contrast, Adams et al. [9] evaluated the use of environmental DNA (eDNA) techniques for surveying turtles, which could greatly expand our ability to locate even very rare species, but will require specialized laboratory-based tools for the foreseeable future.

Three of the SI papers focus on turtle movement patterns. Cochrane et al. [10] took advantage of the development of ever smaller and cheaper GPS units to evaluate their efficacy with wood turtles (*Glyptemys insculpta*), a medium-sized water turtle that also spends considerable time on land. These units offer tremendous advantages over current tracking methods, including high-resolution location data. Ross et al. [11] coupled standard VHS-based radio tracking data with an information theoretic analytical approach to select the best home range models, thus indicating a practical methodology for choosing among the many home range methodologies that have been variously applied to turtles over many decades. Habeck et al. [12] similarly evaluated home range estimates, in this case taking advantage of the many studies of box turtle (*Terrapene carolina* and *T. ornata*) home ranges. Their meta-analysis revealed previously unknown patterns (e.g., female *T. ornata* had smaller home ranges than males, whereas the opposite is true for *T. carolina*, and the home ranges of relocated *T. carolina* females were significantly larger than those of non-relocated females). Rounding out the techniques-focused papers, Craven et al. [13] used gonadal tissue from dead sea turtles to test previous the models used to distinguish immature from mature Kemp's ridley sea turtles (*Lepidochelys kempii)*. Their work will improve the quality of the maturity assessments of live individuals, and therefore result in higher-quality population modeling.

Four papers in this SI were focused on different aspects of demography, a popular topic of long-term turtle field studies. Vanek and Glowacki [14] added another important paper to the growing string of papers evaluating the impact of urbanization on sex ratios, which compares the detrimental impacts of greater male dispersal rates compared to female nesting forays. Their study suggests that urban turtle populations will need management if they are to persist. Garcés-Restrepo et al. [15] conducted one of the few long-term demographic studies of South American freshwater turtles, and found that flooding events associated with global climatic events affected survivorship in the Chocoan River Turtle (*Rhinoclemmys nasuta*). Buchanan et al. [16] conducted a two-species study comparing the population genetic structure and diversity of an abundant generalist, the eastern painted turtle (*Chrysemys picta*), and the rare, more specialized, spotted turtle (*Clemmys guttata*). Surprisingly, in spotted turtles they found weaker than expected genetic signals usually associated with population declines. Feng et al. [17] also studied spotted turtles, using traditional matrix models to determine which vital rates most strongly influenced population growth.

Two papers in this SI focused on nesting behavior, one of the most well-studied aspects of turtle behavior. Escalona et al. [18] evaluated the effects of environmental factors on the timing and synchrony of yellow-spotted Amazon river turtle (*Podocnemis unifilis*) nesting. Not surprisingly, nesting started at the onset of the dry season when river levels were dropping. However, they also found that larger groups of females nested around the time of the full moon, suggesting some degree of social facilitation behavior. Czaja et al. [19] contributed the last paper in this SI on terrapins, reporting the role of nest site microhabitat choice on the resulting nest temperatures and hatching success. The results were more complex than expected in that the effects of microhabitat differed between years with different weather patterns.

The remaining two papers do not neatly fit into the general categories described above. Nekrasova et al. [20] conducted an unusual study, integrating fossil, sub-fossil, and current data to better understand how the range of the European pond turtle (*Emys orbicularis)* has changed since the Holocene. Finally, in an attempt to improve head-starting methodologies, Tetzlaff et al. [21] reported a surprising range of behavioral differences between young box turtles (*T. carolina*) raised with and without environmental enrichment.

In conclusion, this SI highlights the important new research advances in the biology and conservation of turtles. I hope readers will gain new knowledge and direction for their own understanding of this unique group of animals.

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