The Southern Water Snake (Nerodia fasciata): A New and Potentially Invasive Species in Northern California

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Introduction:
Although there are notable exceptions, in general, snakes seem to be ineffective at establishing as invasive species. Of those snakes that have become established outside their native ranges in North America, most are garter snakes (*Thamnophis* spp.) or water snakes (*Nerodia* spp.). The southern water snake (*N. fasciata*) is established in Brownsville, Texas, and this same species has been introduced into the Sacramento region of northern California (Balfour and Stitt. 2002. Herp Rev 33: 150). Here we outline the timeframe of the Sacramento introduction and attributes of the population as determined by removal sampling.

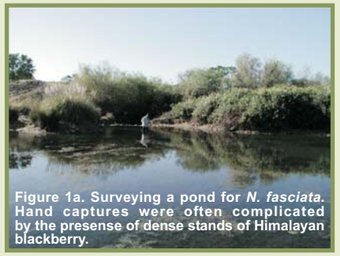

Figure 1a. Surveying a pond for *N. fasciata*. Hand captures were often complicated by the presense of dense stands of Himalayan blackberry.

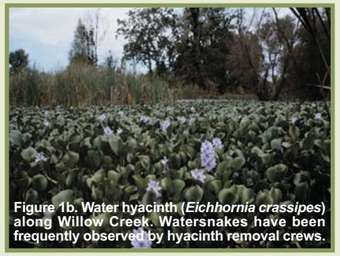

Figure 1b. Water hyacinth (*Eichhornia crassipes*) along Willow Creek. Watersnakes have been frequently observed by hyacinth removal crews.

Figure 6. *Thamnophis elegans* (top left), *T. sirtalis* (bottom left), *Clemmys marmorata* (bottom right), and the introduced *Trachemys scripta* (top right) co-occur with *Nerodia fasciata* in California.

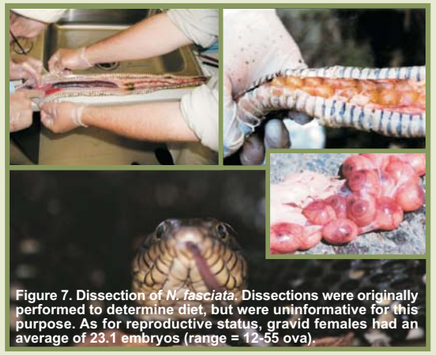

Figure 7. Dissection of *N. fasciata*. Dissections were originally performed to determine diet, but were uninformative for this purpose. As for reproductive status, gravid females had an average of 23.1 embryos (range = 12-55 ova).

Methods:
We captured water snakes by hand primarily during daylight in the months of May, June, July, and August in 1992, 1993, and 1999 through 2004. We dispatched snakes by standard methods and recorded length, mass, and number of ova during necropsies. Additionally, several frozen snakes were obtained from the California Department of Fish and Game (CDFG). Necropsies were initially performed to assess diet only, thus sex was not determined for many snakes, especially from earlier collection dates. We recorded and mapped capture locations, and summarized additional records from CDFG memos and reports.

Figure 2. Aquatic funnel traps employed in 2003 (Casazza, Wylie, and Gregory. 2000. Herp Rev 31:91-92). No captures were made with these in 1940 trap-nights.

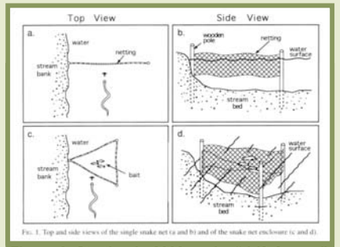

Figure 3. Starting in 2003 snake "drift fences" were employed (Lutterschmidt and Schaeffer. 1996. Herp Rev 27:131-132; figure above from that paper). Four male snakes were captured in 269 trap-nights. However, there was mortality associated with this method.

Results:
Eight adult snakes were captured in 1992 and two in 1993 (CDFG unpub. report). No capture effort was expended between 1993 and 1999. We started opportunistic collection attempts again in 1999. Two snakes were captured in 1999, 32 in 2000, one in 2001, 13 in 2002, and 13 were captured in 2003.

N. fasciata is present in small (<1.0 ha) ponds and narrow, slow moving creeks. Water snakes are most often found on bare or grassy banks; they often escape into dense stands of Himalayan blackberry (*Rubus armeniacus*) and yellow star-thistle (*Centaurea solstitialis*) associated with upland areas, or into aquatic vegetation such as water primrose (*Ludwigia* spp.) and water hyacinth (*Eichhornia crassipes*) (Figure 1b).

The mean mass of adult snakes was 464.3 grams (n = 52, range 70.0 to 1194.0 grams). The mean snout-vent length (SVL) of adults was 71.4 cm (n = 58, range 25.0 to 103.3 cm) (Figure 4). Twenty seven of 29 (93%) known females were found to have ova. The mean number of ova was 23.5 (range = 12 to 55). For years 1999-2002, the number of ova was positively correlated with female SVL (Figure 5; mean SVL = 78.88 cm, n = 27, 95% CI = 74.669 to 83.094 cm). Five snakes gave birth in captivity, one in 1992, a second in 1993, and three in 2002. Mean brood size was 16.6 neonates. Mean neonate SVL was 15.53 cm (n = 53, range = 13.50 to 19.0 cm). Fifteen of 56 adult snakes (26.8%) had partial tails. Partial tails were positively associated with SVL ($t54 = -2.282$, $p = 0.0265$); snakes with partial tails were, on average, 11.10 cm larger.

The currently known northern extent of *N. fasciata* is at Beals Point at Folsom Lake and the southern-most record is at Lake Natoma. The pattern of spread appears to have been along streamcourses upstream and downstream of the original locality (documented circa 1992). Introduced American bullfrogs (*Rana catesbeiana*) and red-eared sliders (*Trachemys scripta*) are often observed, and two native garter snake species (*Thamnophis elegans* and *T. sirtalis*) have been observed in low numbers (Figure 6). Introduced sunfish (*Lepomis* spp.), mosquitofish (*Gambusia affinis*), and very high densities of crayfish (*Procambarus clarkii*) also occur at these sites.

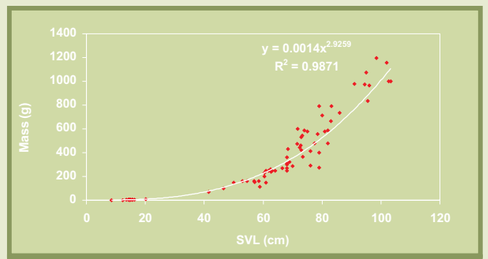

Figure 4. Relationship between body size (SVL) and mass of 97 southern water snakes.

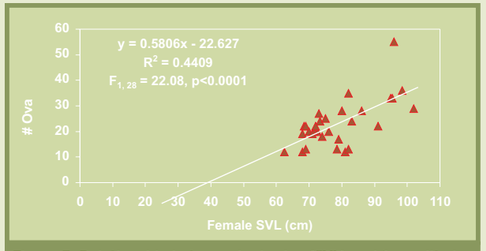

Figure 5. Relationship between body size (SVL) and fecundity in southern water snakes in Sacramento County, California (n = 28).

Discussion:
Size distributions for snakes in our study are similar to those reported by others. However, it seems our sample may be biased toward heavier snakes, most likely females; this apparent bias is most easily explained by our capture methodology, which, prior to 2003, relied primarily on hand capture.

Potential effects—The most immediate potential threat of this introduction may be to the giant garter snake (*Thamnophis gigas*), a state- and federally listed threatened species present downstream in the American River Basin. This garter snake is considered by some to be ecologically equivalent to eastern *Nerodia* (e.g. Rossman, Ford, and Seigel. 1996 The Garter Snakes: Evolution and Ecology. U. of Oklahoma Press, Norman) in that it is highly aquatic, uses emergent vegetation for basking, and forages in the water for food. The giant garter snake uses fresh water marshes, flood basins, and tributaries of California's Central Valley, but its distribution and abundance have been severely reduced (USFWS. 1999. Draft Recovery Plan for the Giant Garter Snake).

Nerodia fasciata is arguably more plastic than *T. gigas* regarding habitat needs. Subspecies of *N. fasciata* may tolerate brackish and seawater, and are known to disperse over land when permanent water dries (Ernst and Ernst. 2003. Snakes of the United States and Canada. Smithsonian Press, Washington, and references therein). *Nerodia fasciata* is a generalized predator of fish, crabs, frogs and toads, salamanders, small snakes, turtles, birds, worms, and crayfish (Ernst and Ernst. 2003). We know little about its dietary habits in northern California, but captive *N. fasciata* readily take *Rana catesbeiana* tadpoles and one snake regurgitated a small sunfish (*Lepomis* sp.) upon capture.

Landscape-level changes in the last 150 years in northern California may have created habitat favorable for *N. fasciata* (Figure 8). Changes in land use including grazing, mining, widespread agriculture, and urban runoff have raised water temperatures and reduced structural complexity in these systems (Moyle. 1976. Inland Fishes of California. University of California Press, Berkeley) which has been detrimental to native vertebrates. California's waterways feature an increasingly "eastern" fauna, and the Sacramento-San Joaquin Delta is no exception (Moyle. 1976). American bullfrogs, introduced from east of the Rocky Mountains, are commonly encountered throughout much of northern California including the study area. The southern water snake appears to be well-suited to persist among these transplanted fauna. Because bullfrogs and southern water snakes co-occur in their native ranges we might expect water snakes to be better adapted than giant garter snakes at 1) using bullfrogs as a prey base and 2) avoiding predation by bullfrogs at early life history stages. The same may be true for the interactions between introduced predatory fish, crayfish, and the two snake species.

The generalist nature of *N. fasciata*'s diet and habitat associations, the snake's high fecundity, a physiological tolerance for brackish water, and a tendency to disperse over land all combine to make this snake a formidable introduced predator in northern California. *N. fasciata* has the potential to populate other aquatic systems in California including areas populated by other threatened and endangered wildlife. Additional *Nerodia* introductions have since been documented in the San Francisco Bay area as well as southern California (Fuller and Trevett, 2006. Herp Review 37:363) and Phoenix, Arizona. For this reason, we suggest that monitoring and eradication efforts be increased in the hopes of controlling the spread of *Nerodia* in California and elswhere. We are working with the California Department of Fish and Game and the U.S. Fish and Wildlife to continue efforts to control the Folsom population and are attempting to expand efforts to evaluate the current status of additional documented introduced populations of the genus *Nerodia* in other parts of California.

Figure 8. Historic (1949) and recent aerial photographs of the study area. The area was extensively mined for gold and other ores for nearly 100 years. White signatures in 1949 photo represent dredger tailings, the result of past gold mining.

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