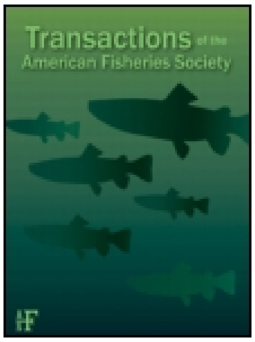

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Transactions of the American Fisheries Society

ISSN: 0002-8487 (Print) 1548-8659 (Online) Journal homepage: http://www.tandfonline.com/loi/utaf20

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To cite this article: John S. Odenkirk & Mike W. Isel (2016) Trends in Abundance of Northern Snakeheads in Virginia Tributaries of the Potomac River, Transactions of the American Fisheries Society, 145:4, 687-692, DOI: 10.1080/00028487.2016.1149516

To link to this article: http://dx.doi.org/10.1080/00028487.2016.1149516

Published online: 15 Jun 2016.

Transactions of the American Fisheries Society 145:687–692, 2016

ISSN: 0002-8487 print / 1548-8659 online
DOI: 10.1080/00028487.2016.1149516

NOTE

Trends in Abundance of Northern Snakeheads in Virginia Tributaries of the Potomac River

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Abstract
A population of nonnative Northern Snakeheads *Channa argus* was documented in the Potomac River system during 2004. We estimated relative abundance (fish/h of boat electrofishing) for up to 12 years in four Virginia creeks within and downstream of the original area of colonization. Population estimates were also calculated for adult Northern Snakeheads in Little Hunting Creek (one of the four study creeks). Relative abundance increased dramatically after colonization, but trends suggest that increases in abundance may have slowed. Population estimates for Little Hunting Creek (12–22 fish/ha) declined each year from 2013 to 2015, supporting the assertion that Northern Snakehead density increases have slowed or that density has stabilized in some creeks.

The nonnative Northern Snakehead *Channa argus* was first documented in the tidal Potomac River system in 2004 (Odenkirk and Owens 2005). The range of this population subsequently expanded, and relative abundance estimates from electrofishing and angler reports indicated that fish density also increased (Odenkirk and Owens 2007). Concern remains over the potential for introduced Northern Snakeheads to exert biological and ecological impacts on native and naturalized fish populations and communities (Courtenay and Williams 2004; Herborg et al. 2007; Poulos et al. 2012). Despite copious media reports and popular publications that have sensationalized the invasive characteristics of Northern Snakeheads, the scientific literature is devoid of studies that have evaluated the ecological impacts of this species. Specific impacts attributable to Northern Snakeheads have not been observed in host fish communities, but concern persists, especially since the tidal freshwater Potomac River supports an extensive and acclaimed fishery for Largemouth Bass *Micropterus salmoides* (Markham et al. 2002). One of the most germane factors that could influence the extent of potential deleterious impacts is the density or abundance of Northern Snakeheads in newly colonized waters. Exotic species commonly exhibit increases in abundance immediately after establishment, but trends are not always consistent. Typically, explosive population growth is observed, followed by a rapid decline, and eventually the nonnative population reaches an equilibrium with its environment (Fury and Morello 1996).

The primary objective of this study was to track the early colonization density of Northern Snakeheads in several Virginia tributaries of the Potomac River over the period of record (2004–2015) by using a relative abundance metric. Our secondary objective was to calculate a short time series of Northern Snakehead population estimates for one of the tributaries so as to provide an absolute abundance estimate and to gain additional insight into potential temporal changes in density.

METHODS

Northern Snakeheads were captured during daytime DC electrofishing surveys conducted by the Virginia Department of Game and Inland Fisheries. Electrofishing was performed from a 5.2-m, aluminum johnboat by using twin anodes with six droppers each. The pulse box was a Smith-Root Type VI-A that was set at 884-V DC, run at 7 A, and powered by a 5,000-W generator. The electrofishing crew consisted of a driver and two netters. We sampled four tidal creeks in Virginia (freshwater tributaries of the Potomac River) annually between March and September (from north to south): Little Hunting, Dogue, Pohick, and Aquia creeks (Figure 1).

Electrofishing was concentrated in shallow water (<2 m) along channel margins and in embayments along aquatic vegetation transition lines (e.g., submersed to floating). Sampling methods differed in accordance with the size of the creek.

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Received October 6, 2015; accepted January 26, 2016

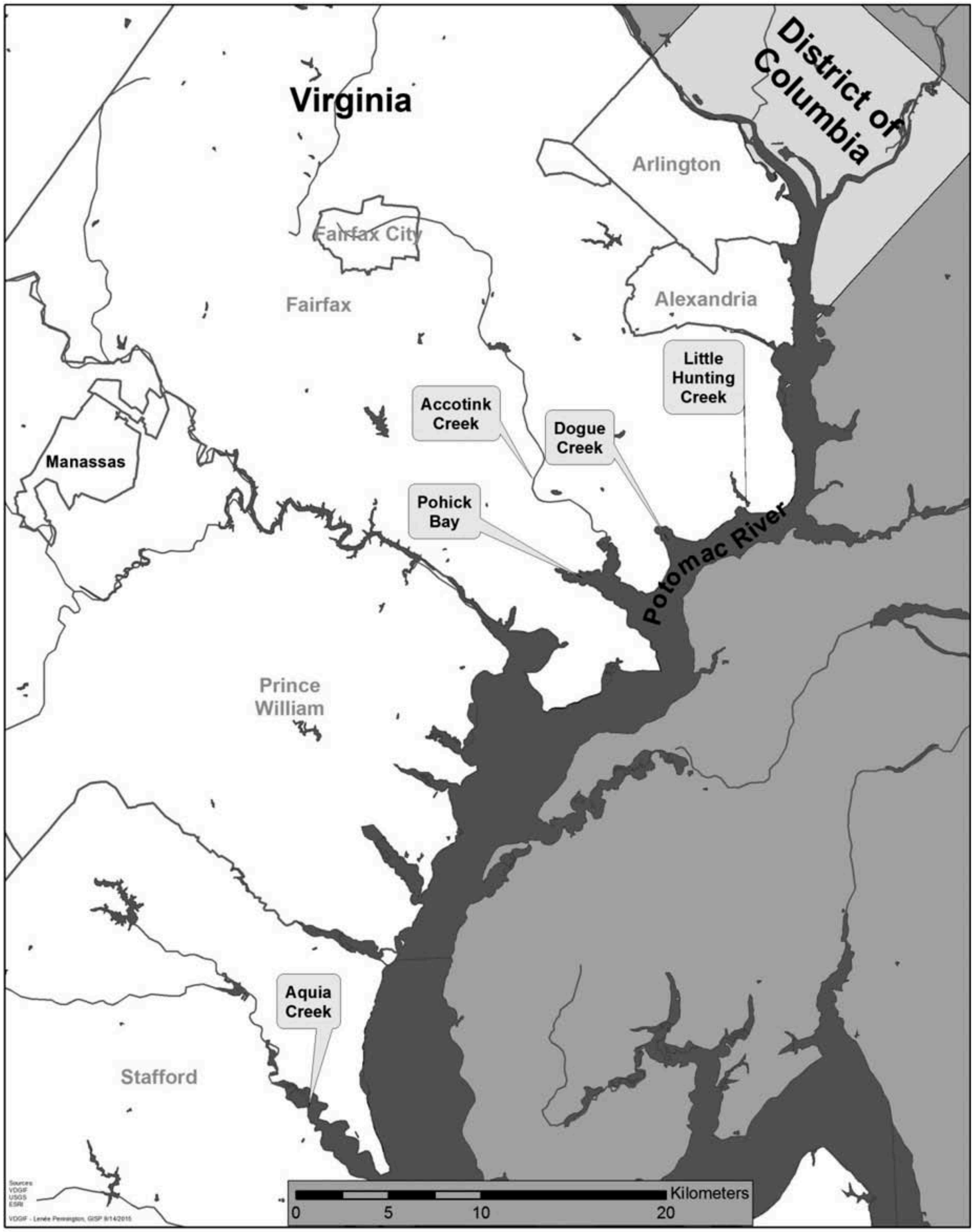

FIGURE 1. Map of the tidal Potomac River and its Virginia tributaries that were sampled for nonnative Northern Snakeheads.

Little Hunting Creek (the smallest tributary) was sampled upstream along one shoreline until shallow depth prohibited further travel, at which point the crew would turn and sample downstream along the opposite shoreline, thus sampling the entire creek at each visit. The other three creeks were larger and could not be fully sampled during a single trip. In those cases, the same creek reaches that were familiar to boat operators were sampled at each visit, essentially serving as fixed stations. Each trip to each creek was considered a sampling unit; the number of fish collected and the electrofishing effort were recorded.

Relative abundance estimates (fish collected per hour of boat electrofishing) were calculated for each creek. Using log-transformed catch data (fish/h), means were compared via ANOVA followed by Tukey's post hoc test in SYSTAT (Wilkinson 1997). The significance level α was set at 0.05.

The three northern creeks (Little Hunting, Dogue, and Pohick creeks) represent the original epicenter of distribution and likely have supported a self-sustaining Northern Snakehead population since about 2000 (Odenkirk and Owens 2005). It is believed that the three creeks have hosted Northern Snakeheads for the longest period of time of any self-sustaining Northern Snakehead population in North America. Based on verified angler reports and sampling data, Aquia Creek (about 27 km south of Pohick Creek) was apparently colonized about 3 years later (Northern Snakeheads were first documented in each core creek during 2004 and in Aquia Creek during 2007; J. S. Odenkirk, unpublished data). Creek selection was random, but Little Hunting Creek was sampled more frequently during 2013–2015 due to increased priority for mark–recapture population estimates.

Northern Snakehead population estimates were calculated for "adult" fish in Little Hunting Creek over three consecutive years (2013–2015) by using the Schnabel method (Hayes et al. 2007). Age-1 and older (>260 mm TL) Northern Snakeheads were considered to be adults (Odenkirk et al. 2013). Little Hunting Creek was chosen based on its relatively small size (28 ha) and isolated channel morphology, including a constricted mouth—unlike the characteristics of many other regional tributaries. The creek's morphology was anticipated to minimize immigration and emigration based on observed Northern Snakehead behavior (Lapointe et al. 2012). Multiple sampling trips were made annually; each collected Northern Snakehead received a uniquely marked T-bar anchor tag at the base of the dorsal fin and was released. Tagged fish that were collected with a prior year's tag were treated as "new" fish for the purposes of annual population estimates. The Schnabel population matrix was edited as appropriate for fish that were known to have been harvested (i.e., removed from the population) by anglers, but the matrix was not otherwise adjusted for nonreporting, exploitation, or movement. We felt that this closed population estimate was appropriate based on past telemetry work and tagging studies and based on the origin of angler-caught fish tagged in Little Hunting Creek during this study. Lapointe et al. (2012) concluded that Northern Snakeheads remained in restricted home ranges throughout the year despite the fact that a considerable proportion of individuals dispersed (almost exclusively in the spring). In the present study, anglers reported harvesting 38 Northern Snakeheads within tagging years, including 34 individuals from Little Hunting Creek (89%), suggesting that emigration from the creek was minimal.

RESULTS

Trends in the mean relative abundance of Northern Snakeheads varied between creeks, but a pattern of increasing abundance followed by possible stabilization was prevalent in all creeks except Aquia Creek (Figure 2). Maximum catch rate was observed either during 2012 or 2013 except in Aquia Creek, where the catch rate was highest during 2014. However, high variability in catch rates (and low sample sizes in some cases) resulted in few significant differences (Tables 1–4). Only Pohick Creek had no significant differences between years, but this creek also had the lowest sample size. Data from other creeks supported temporal increases in abundance after the initial sample years, and comparisons of samples from 2014 and 2015 detected no significant differences (except for Aquia Creek).

The Northern Snakehead population estimates for Little Hunting Creek displayed a declining trend. The estimated number of adults declined each year from 617 individuals in 2013 (22 fish/ha) to 350 individuals in 2015 (12.5 fish/ha; Table 5).

DISCUSSION

These data contribute important insight into Northern Snakehead abundance patterns during their early colonization phase in a large tidal river system. Although the data were

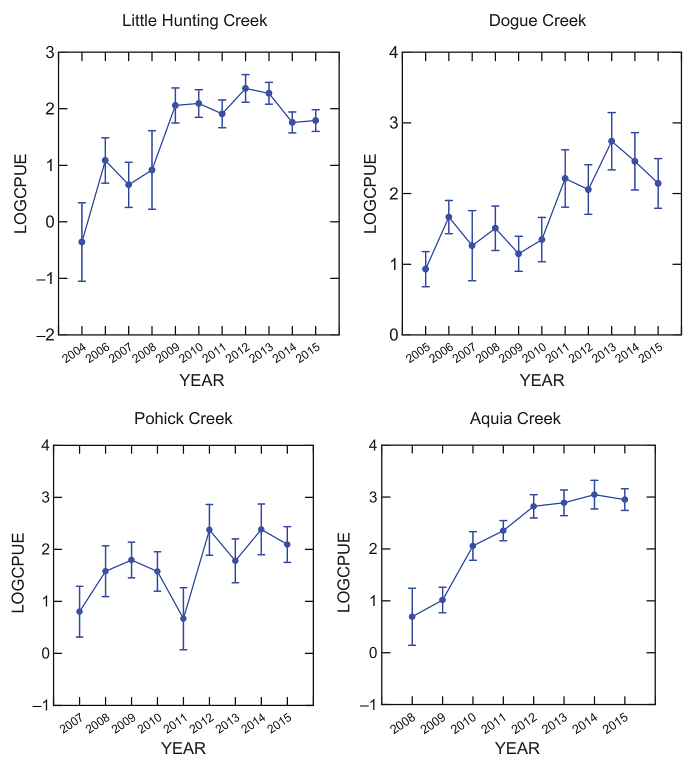

FIGURE 2. Log-transformed mean (±SE) relative abundances (fish/h of boat electrofishing) of nonnative Northern Snakeheads in four Virginia tributaries of the Potomac River.

TABLE 1. Mean estimates of Northern Snakehead relative abundance (fish/h of boat electrofishing) in Little Hunting Creek, Virginia (*N* = number of sampling trips). Means with the same number and lowercase letter are significantly different (ANOVA: α = 0.05).

Year	*N*	Mean	SD
2004	2	0.4	0.5
		1(zyx)	
2005	3	0.0	
2006	3	3.1	1.2
2007	3	2.7	2.7
		2(zy)	
2008	1	2.5	
2009	7	6.0	5.2
2010	8	9.7	5.3
		1(z)	
2011	8	7.7	3.3
2012	8	11.3	4.6
		1(y)2(z)	
2013	12	11.5	6.1
		1(x)2(y)	
2014	14	7.7	5.6
2015	14	7.5	4.2

variable, trends suggested that increases in abundance slowed, especially in waters where Northern Snakeheads had been established longest. Based on the age structure of fish collected in 2004, Northern Snakeheads likely had inhabited the northern three creeks for at least 15 years (Odenkirk and Owens 2005). These trends were similar to those described by Williamson (1996), wherein an invading species attains a peak density and then declines—a trend that is often referred to as "boom and bust." In Willow Lake, New York, the abundance of Northern Snakeheads was highest in 2006, the year after the species was

TABLE 2. Mean estimates of Northern Snakehead relative abundance (fish/h of boat electrofishing) in Dogue Creek, Virginia (*N* = number of sampling trips). Means with the same lowercase letter are significantly different (ANOVA: α = 0.05).

Year	*N*	Mean	SD
2005	8	2.9 z	1.4
2006	9	7.1	5.6
2007	2	3.8	1.8
2008	5	5.7	3.8
2009	8	4.0 y	2.7
2010	5	4.3	2.1
2011	3	10.9	8.0
2012	4	8.8	4.4
2013	3	19.0 zy	12.5
2014	3	12.0	3.6
2015	4	10.0	7.3

TABLE 3. Mean estimates of Northern Snakehead relative abundance (fish/h of boat electrofishing) in Pohick Creek, Virginia (*N* = number of sampling trips). Means were not significantly different (ANOVA: α = 0.05).

Year	*N*	Mean	SD
2007	3	2.4	1.1
2008	3	5.9	4.8
2009	8	5.8	5.0
2010	5	8.1	8.4
2011	2	2.4	2.0
2012	4	12.0	14.6
2013	5	5.6	4.5
2014	3	11.3	3.8
2015	6	9.0	3.9

TABLE 4. Mean estimates of Northern Snakehead relative abundance (fish/h of boat electrofishing) in Aquia Creek, Virginia (*N* = number of sampling trips). Means with the same number and letter are significantly different (ANOVA: α = 0.05).

Year	*N*	Mean	SD
2007	1	0.0	–
2008	1	2.0	–
		1(zyxw)	
2009	5	3.6	2.9
		2(zyxwv)	
2010	4	9.8	9.8
2011	8	11.3	4.8
		2(z)	
2012	6	18.3	9.8
		1(z)2(y)	
2013	5	21.2	13.3
		1(y)2(x)	
2014	4	21.3	3.6
		1(x)2(w)	
2015	7	20.7	14.5
		1(w)2(v)	

TABLE 5. Estimated adult population (with 95% confidence interval [CI]) of Northern Snakeheads in Little Hunting Creek (28 ha), Virginia. Estimates were derived by using the Schnabel mark–recapture technique.

Year	Trips	Number tagged	Number recaptured	Adult *N*	95% CI
2013	12	162	26	617	441–1,029
2014	14	111	13	567	367–1,242
2015	14	85	11	350	220–854

discovered in the lake; in Meadow Lake, New York, abundance peaked during 2008, 3 years after the species' discovery in that system (Cohen and MacDonald 2016). Abundance declined afterward and appeared to stabilize at a lower level. In Lake Biwa, Japan, Northern Snakeheads also experienced a phase of rapid population growth after introduction, but their abundance declined soon thereafter and the species is now considered rare in that lake (M. Grygier, Lake Biwa Museum, personal communication). Northern Snakehead abundance in Aquia Creek, which was colonized about 3 years after the three northern creeks, appeared to have a more recent rate of increase. Several factors may have operated (e.g., low intraspecific density; and a paucity of predators and parasites) to provide enhanced survival, recruitment, and growth in this exotic fish during the early years of its colonization (Jiao et al. 2009).

Trends in adult population estimates for Little Hunting Creek during 2013–2015 appeared to support data from relative abundance sampling and suggested that Northern Snakehead abundance not only stopped increasing but possibly decreased in some areas, although the magnitude of the decline was greater for population estimates between 2014 and 2015. Biases associated with violating the assumptions of mark–recapture procedures should have been consistent among years, allowing us to track temporal changes in the populations. Additionally, population estimates from Little Hunting Creek provided the first known estimates of Northern Snakehead density, which ranged from about 12 to 22 fish/ha. All of Little Hunting Creek contained habitat that was suitable for Northern Snakeheads (Owens et al. 2008), so these estimates likely represent the approximate numbers of adults in the creek during the years surveyed.

Our relative abundance and population estimates may have been affected by variable recruitment, as some aspects of Northern Snakehead population dynamics are still largely unknown. For riverine fish species, high recruitment variability is usually the rule rather than the exception (e.g., Buynak and Mitchell 2002; Greenlee and Lim 2011), and both strong and weak cohorts of Northern Snakeheads have been recognized recently based on evaluation of catch curve residuals (Odenkirk, unpublished data). Increases in recreational and commercial harvest may also have impacted our indices of abundance. Media attention and efforts by some governmental agencies to exploit Northern Snakehead stocks have likely led to increased harvest of this species in the Potomac River, which is also adjacent to Maryland and Washington, D.C. (near our study sites), where the commercial sale of Northern Snakeheads is legal.

It is unclear how many years may be required for Northern Snakeheads to reach equilibrium, but such temporal trends are likely to be highly variable and dependent on numerous factors, such as productivity, habitat, life history, exploitation, and community structure. The Flathead Catfish *Pylodictis olivaris*, another nonnative predatory fish, displayed distinct and recurrent population booms and declines over 22 years, suggesting that abundance either had not reached equilibrium or would remain dynamic (Kaeser et al. 2011). Introduced Blue Catfish *Ictalurus furcatus* in two Virginia rivers had not reached equilibrium even after 35 years (Greenlee and Lim 2011). Thus, it seems likely that future decades will hold further changes for Northern Snakehead abundance. However, it is noteworthy that the upward trajectories in Northern Snakehead abundance, which were prevalent at the early stages of colonization, may have slowed. If current abundance, density, or both do not appreciably increase, then this introduction might have minimal impacts on the ecology of the Potomac River. Since 1854, at least 30 nonnative fish species have been introduced into the lower Potomac River basin, including six Eurasian species—of which four (e.g., the Northern Snakehead) remain established today (Starnes et al. 2011).

ACKNOWLEDGMENTS

This study was funded in part through Federal Aid in Sportfish Restoration Grant F-111-R. We thank the Virginia Department of Game and Inland Fisheries biologists, conservation police officers, technicians, and volunteers who assisted in field collections. Josh Newhard (U.S. Fish and Wildlife Service) managed the angler tag returns. Helpful reviews were provided by Frank Rizzo and Bret Weir; Lenee Pennington produced the map.

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