Northern Snakehead Movement and Distribution in the Tidal Potomac River System

Stephen J. Owens, *Virginia Department of Game and Inland Fisheries, 1320 Belman Road, Fredericksburg, VA 22401*

John S. Odenkirk, *Virginia Department of Game and Inland Fisheries, 1320 Belman Road, Fredericksburg, VA 22401*

Robert Greenlee, *Virginia Department of Game and Inland Fisheries, 3801 John Tyler Memorial Highway, Charles City, VA 23030*

Abstract: Radio transmitters were implanted in 20 northern snakeheads (*Channa argus*) in April 2006 to evaluate movement and habitat use of this newly established population. Eight fish were monitored through 15 September 2006, and five transmitters remained active until the conclusion of the study in January 2007. Linear movement was summarized for nine fish frequently found (7–28 contacts; mean 20, SD = 8). Mean movement was 541 m (SD = 356) and the mean "maximum recorded distance" was 2901 m (SD = 2050). Linear movement for fish tracked during the spawning period was significantly different between individuals (ANOVA, $P = 0.01$), while post spawn movement was not. Northern snakeheads moved more during the post spawn period than during spawning months (March–September). Northern snakeheads showed a habitat preference for hydrilla (*Hydrilla verticillata*, 24.0%), floating docks (22.8%), and milfoil (*Myriophyllum, spicatum*, 21.6%) during this study. Regardless of habitats occupied, snakeheads were found exclusively in water less than 1.2 m deep with most contacts made in water less than 0.6 m deep.

Key words: northern snakehead, exotic introductions, tidal freshwater rivers

Proc. Annu. Conf. Southeast. Assoc. Fish and Wildl. Agencies 62: 161–167

The northern snakehead (*Channa argus*) is a piscivorous fish native to eastern Asia that has been introduced throughout central Asia and Japan and, most recently, the United States (Courtenay and Williams 2004). Since 2004, northern snakeheads have become established in the Virginia/Maryland tidal freshwater portion of the Potomac River downstream of Washington, D.C. (Odenkirk and Owens 2005). The tidal Potomac River supports an extensive recreational fishery for largemouth bass (*Micropterus salmoides*) that is nationally acclaimed (Markham et al. 2002). The reputation of the northern snakehead to alter aquatic ecosystems (Courtenay and Williams 2004), sensational media reporting, and resulting angler concern provided the impetus to learn more about the potential impacts of this exotic introduction on existing fish populations. A prerequisite to evaluate potential ecosystem impacts was the need to gather basic life history and behavioral characteristics including habitat preferences.

A paucity of literature concerning northern snakehead behavior in North America, particularly in a large tidal river system, underscored the need to gain an understanding of northern snakehead biology. Thus, we initiated a telemetry study in April 2006 to investigate movement and habitat use of northern snakeheads in the tidal freshwater Potomac River. This paper details the results of the first known telemetry study of northern snakeheads.

Methods

Boat electrofishing was used during April 2006 to collect 20 northern snakeheads for transmitter implantation from Dogue Creek (Fig. 1). Dogue Creek is a tidal tributary of the Potomac River adjacent to Ft. Belvoir in Fairfax County, Virginia, and appeared to be the epicenter of the northern snakehead population (Odenkirk and Owens 2005). A Smith Root Type VI-A pulse box was set at maximum output (1,061 V) and operated at 5–6 A. All northern snakeheads collected were placed in a covered live well prior to transmitter implantation.

Two transmitter sizes were implanted in 20 adult snakeheads of varying sizes due to concerns about the ability to collect 20 large, adult fish (Table 1). Both tag sizes operated on a frequency range of 150.000–151.999 MHz. Five 8-g transmitters (ATS, Model F1820) with a pulse rate of 40 ppm and a battery functionality of 264 days (guaranteed 132 days) were implanted in fish at least 454 g, and fifteen 13-g transmitters with a pulse rate of 40 ppm and a battery functionality of 654 days (guaranteed 327 days) were implanted in fish at least 908 g. Transmitters were implanted between 20 April and 1 June 2006, with most fish receiving a tag on 20 April and 27 April. Northern snakeheads implanted with small tags had a mean total length of 446 mm (SD = 65 mm) and mean weight of 872 g (SD = 387 g). Fish implanted with larger tags had a mean total length of 611 mm (SD = 66 mm) and mean weight of 2426 g (SD = 928 g). Radio transmitters implanted did not exceed 2% of body weight (Winter 1996). Clove oil was used to anesthetize fish (Anderson et al. 1997), and a 2-cm incision was made through the lateral body wall anterior to the vent (Hart and Summerfelt 1975). A radio transmitter was doused in 10% povidone-iodine solution to act as a topical microbicide and inserted into the abdominal cav-

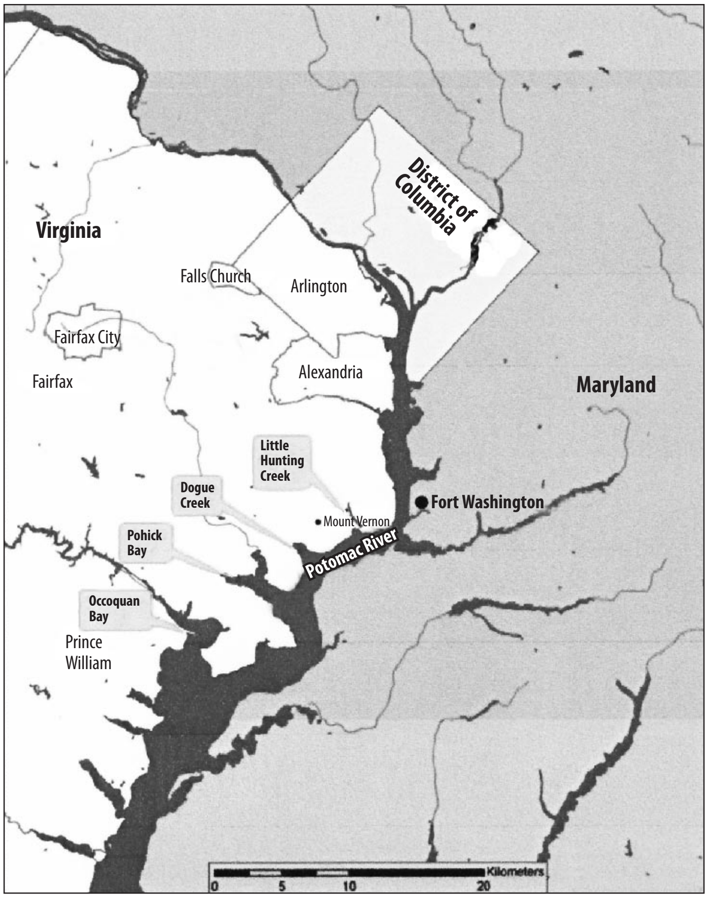

Figure 1. Map of study area showing Virginia tidal Potomac River tributaries where radio-tagged northern snakehead movement was documented April 2006–January 2007.

Table 1. Total length (mm) and weight (g) for northern snakeheads collected 18–20 April 2006 from Dogue Creek and implanted with radio tags. Smaller 8-g tags are denoted by "*". All other tags were 13 g. Number of relocations post tagging equals contacts. Contact longevity is expressed in days.

TL (mm)	WT (g)	Radio frequency (MHz)	Tag date	Final contact	*n* contacts	Contact longevity
377	472	0.024*	20 Apr 2006	13 Jul 2006	13	83
488	1091	0.054*	27 Apr 2006	15 Sep 2006	20	138
387	520	0.073*	20 Apr 2006	13 Jul 2006	13	83
446	886	0.094*	27 Apr 2006	15 Sep 2006	17	138
530	1389	0.115*	27 Apr 2006	13 Jul 2006	11	76
660	2935	1.024	20 Apr 2006	4 Jan 2007	17	254
602	2194	1.045	27 Apr 2006	4 Jan 2007	26	247
557	1785	1.064	27 Apr 2006	24 May 2006	3	27
655	2830	1.084	27 Apr 2006	2 Oct 2006	9	155
740	4598	1.103	27 Apr 2006	4 Jan 2007	26	247
605	2386	1.123	27 Apr 2006	13 Jul 2006	11	76
557	1534	1.144	20 Apr 2006	13 Jul 2006	12	83
495	1117	1.162	20 Apr 2006	27 Apr 2006	1	7
519	1284	1.183	27 Apr 2006	4 Jan 2007	28	247
646	2394	1.204	1 Jun 2006	13 Jul 2006	6	42
662	3243	1.223	20 Apr 2006	13 Jul 2006	11	83
679	3547	1.244	27 Apr 2006	4 Jan 2007	26	247
575	1740	1.264	20 Apr 2006	13 Jul 2006	12	83
646	2750	1.285	27 Apr 2006	13 Jul 2006	11	76
572	2047	1.301	27 Apr 2006	22 Jun 2006	7	55

ity, and the incision was closed with surgical staples (Mortensen 1990). Surgical instruments were rinsed in 10% povidone-iodine solution prior to use. Each fish was also tagged with a sequentially numbered T-bar anchor tag marked "US$50 Reward" and contact information. Fish were allowed to recover in a net pen for approximately 20 minutes until equilibrium returned prior to release (Palmer et al. 2005, Popoff and Neumann 2005). The head of each fish was propped out of the water during the recovery phase to prevent drowning due to the northern snakehead being an obligate air breather (Courtenay and Williams 2004).

Tracking was conducted using an ATS scanning receiver with a directional loop antenna from a jon boat on a fixed weekly basis April-October 2006. The location of each fish was recorded with a Garmin 12XL handheld GPS unit. Habitat parameters were also recorded with each contact and included water temperature, depth, and physical cover which included aquatic vegetation. Tracking frequency was extended to every two weeks from October 2006–January 2007, due to personnel constraints. Due to the tidal nature of the system (diel cycles of 0.64 m) and heavy summer vegetation, a Mud Buddy 29-hp hyperdrive motor system mounted on a 5.2-m Gatortrax boat was typically used that allowed for navigation in very shallow, muddy, or weed infested environs. Searches began by boat from near Fort Washington, Maryland, downriver to Pohick Bay, Virginia. Searches were expanded to look for missing fish from the Alexandria, Virginia, area downstream to Occoquan Bay, Virginia (Figure 1). Tags consecutively contacted in the exact same location for periods beyond 30 days were assumed to have been expelled or mortalities (Firehammer and Scarnecchia 2006).

Location data for individual fish were used to calculate range, which included mean range, linear movement, and seasonal home range (spawn and post spawn) (Daugherty and Sutton 2005, Popoff and Neumann 2005). Mean range was calculated by averaging the extreme upstream and downstream locations (Clapp et al. 1990, Bettinger and Bettoli 2002, Popoff and Neumann 2005). The spawn period was defined as tag deployment–14 September 2006 and post spawn was defined as 15 September 2006–4 January 2007 (Courtenay and Williams 2004, Odenkirk and Owens 2007). Linear movement was compared between fish using analysis of variance (ANOVA) for the spawn, post spawn, and entire study periods and significance level was set at α <0.05. Movement data were log transformed because linear telemetry data rarely meet criteria of a normal distribution (Rogers and White 2007). Movement patterns were characterized utilizing the "adaptive kernel" method proposed by Worton (1989). Movement was defined as either within the core or overall home range. The core area was calculated as a 50% kernel, and the home range was calculated as a 95% kernel (Worton 1989).

Results

Fifteen of the 20 fish implanted with transmitters were located more than 10 times during the study period which spanned from 20 April 2006–4 January 2007 (Table 1). Radio frequencies unaccounted for during the study may have been related to tag expulsion, angler harvest, emigration, or mortality. Repeated undocumented movement for a particular fish over 30 days was used for classification as a shed tag or mortality. One tagged fish (1.162) was caught by an angler on 22 April 2006 during a bass fishing tournament. Eight fish were monitored through 15 September 2006 (~138 days post release) (Table 1). Only five active transmitters remained upon the conclusion of field monitoring 4 January 2007 which ranged 247–254 d post release (Table 1). Fourteen unaccounted transmitters may be explained by tag expulsion, dead batteries, mortalities, or fish may have emigrated out of the study area.

Linear movement was summarized for nine fish frequently found with a contact longevity ranging from 55–254 days post implantation (Table 2). These fish had a frequency of contacts per fish that ranged from 7–28 (mean 20, SD = 8) (Table 2). Mean movement was 541 m (SD = 356) and the mean "furthest point distance" was 2901 m (SD = 2050). Individual movements remained localized throughout the study period for most fish monitored (Fig. 2); however, frequencies 1.045 and 1.244 were exceptions (Fig. 3). Mean movement for 1.045 (829 m, SD = 880) and 1.244 (908 m, SD = 1024) were significantly different from the overall mean of 541 m (Table 3). Additionally, the maximum recorded distance for 1.045 was 5205 m, which was almost double the overall mean of 2901 m (Table 2, Fig. 3). Mean movement (908 m) and furthest point distance (6123 m) was significantly greater for 1.244 as compared to the nine fish evaluated (Table 2, Table 3, Fig. 3). Linear movement for fish tracked during the spawning period was significantly different between individuals (Table 3). However, linear movement during the post-spawn period was not significantly different (Table 3).

Continuous data were only available for four transmitters throughout the spawn and post spawn period. Statistical tests examining home range were not available due to small sample size and differences among individuals. Movement patterns during the spawn within the core range had a mean of 5.6 ha (SD = 8.9) and ranged 0.8–18.9 ha (Table 4). Mean core ranges increased post spawn to 115.5 ha (SD = 127.3) and ranged 50.5–298.3 ha (Table 4). Core range was considerably larger for 1.045 and 1.244 both during the spawn and post spawn periods than was documented for 1.103 or 1.183 (Table 4). For instance, the core area for 1.244 during the spawn was three times the mean and during the post spawn, the core area was 2.5 times the mean (Table 4). Home range during the spawn averaged 60.4 ha (SD = 101.6) and ranged 5.1–212.6 ha (Table 4). Mean post spawn home range increased to 413.8 ha (SD = 384.3) and ranged 48.8–944.5 ha (Table 4). As documented with core area, home range for 1.045 and 1.244 were greater than 1.103 and 1.183.

Table 2. Movement summary for northern snakeheads in the tidal Potomac River system, April 2006–January 2007. Contacts = number of relocations post tagging. Contact longevity is expressed in days. Movement and distance measurements expressed in meters.

Radio tag	Tag date	Contacts	Days	Mean movement	Max movement	Furthest point distance
0.054	27 Apr 2006	20	138	154 (139)	517	703
0.094	27 Apr 2006	17	138	386 (366)	1383	1743
1.024	20 Apr 2006	17	254	352 (177)	711	856
1.045	27 Apr 2006	26	247	829 (880)	3264	5205
1.084	27 Apr 2006	9	155	1126 (1609)	4911	4934
1.103	27 Apr 2006	26	247	147 (121)	440	1057
1.183	27 Apr 2006	28	247	276 (367)	1586	2710
1.244	27 Apr 2006	26	247	908 (1024)	4509	6123
1.301	27 Apr 2006	7	55	687 (662)	1636	2775

Table 3. Mean linear movement (m) for northern snakeheads monitored in the tidal Potomac River system from 27 April 2006–4 January 2007. Data were log10 transformed for analysis. Column means with the same letter were significantly different: Distance = ANOVA; $F_{8,156} = 4.82$, $P < 0.0001$. Distance (spawn) = ANOVA; $F_{8,113} = 4.01$, $P < 0.0001$. Distance (post spawn) = ANOVA; $F_{4,34} = 2.73$, $P < 0.0001$.

Radio tag	Distance (27 Apr 2006–4 Jan 2007)	Distance (spawn) (27 Apr 2006–8 Sep 2006)	Distance (post spawn) (15 Sep 2006–4 Jan 2007)
0.054	154^{A}	161^{A}	
0.094	386	365	
1.024	352	711	307
1.045	829^{AB}	754^{B}	1020
1.084	1126^{AC}	454	
1.103	147^{BCD}	101^{BC}	252
1.183	276^{CE}	142^{D}	584
1.244	908^{ADE}	944^{ACD}	828
1.301	687		

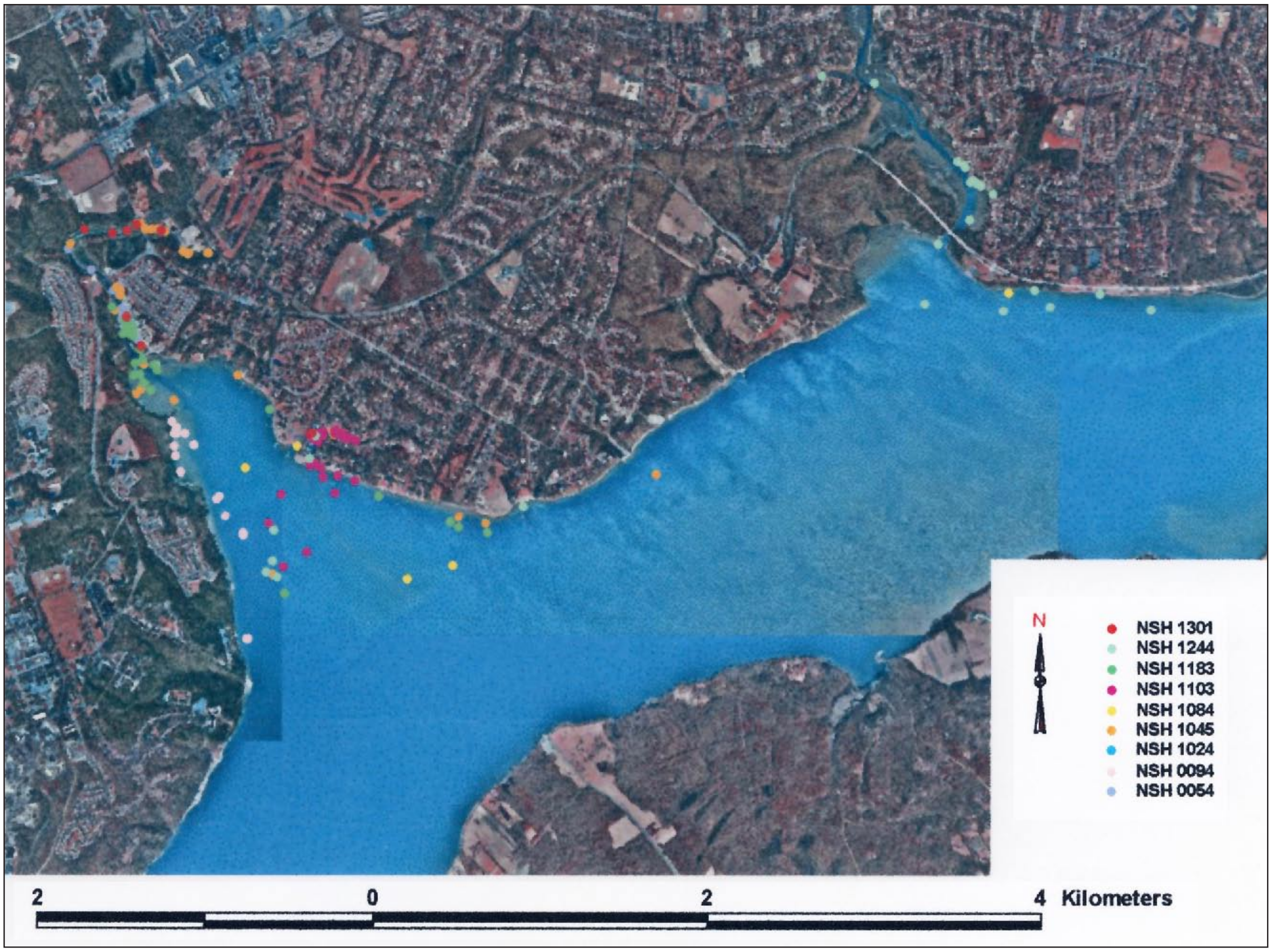

Figure 2. Movement throughout the Potomac River system for nine fish frequently contacted throughout the study. Contact longevity ranged from 55–254 days post implantation. Colored dots correspond to specific frequencies.

Table 4. Northern snakehead movement patterns depicted as core (50% kernel) and home range (95% kernel) areas (hectares) for radio-tagged fish with continuous contact through the spawning period (tag deploy–8 September 2006) and the post spawning period (15 September–4 January 2007). CA = Core Area. HR = Home Range.

Radio tag frequency	Spawn–CA (ha)	Post spawn–CA (ha)	Spawn–HR (ha)	Post spawn–HR (ha)
1.045	1.9	101.6	17	415.9
1.103	0.9	11.5	5.1	48.8
1.183	0.8	50.5	6.8	245.8
1.244	18.9	298.3	212.6	944.5
Mean (SD)	5.6 (8.9)	115.5 (127.3)	60.4 (101.6)	413.8 (384.3)

Table 5. Habitat utilization of radio-tagged northern snakeheads in the Potomac River system. Spawn period defined as tag deployment–8 September 2006. Post spawn period defined as 15 September–4 January 2007. Total equals spawn and post spawn periods combined.

	Tracking period					
	Spawn		Post spawn		Total	
Habitat type	% use	Rank	% use	Rank	% use	Rank
Bulkhead	0.8	9	0.0	6	0.6	9
Floating dock	29.3	1	2.6	4	22.8	2
Hydrilla	22.8	2	23.1	2	24.0	1
Milfoil	8.9	5	64.1	1	21.6	3
Natural wood	8.9	6	0.0	7	6.6	6
Pier	6.5	7	7.7	3	6.6	7
Root wad	1.6	8	0.0	8	1.2	8
Spatterdock	11.4	3	2.6	5	9.6	4
Stream channel	9.8	4	0.0	9	7.2	5

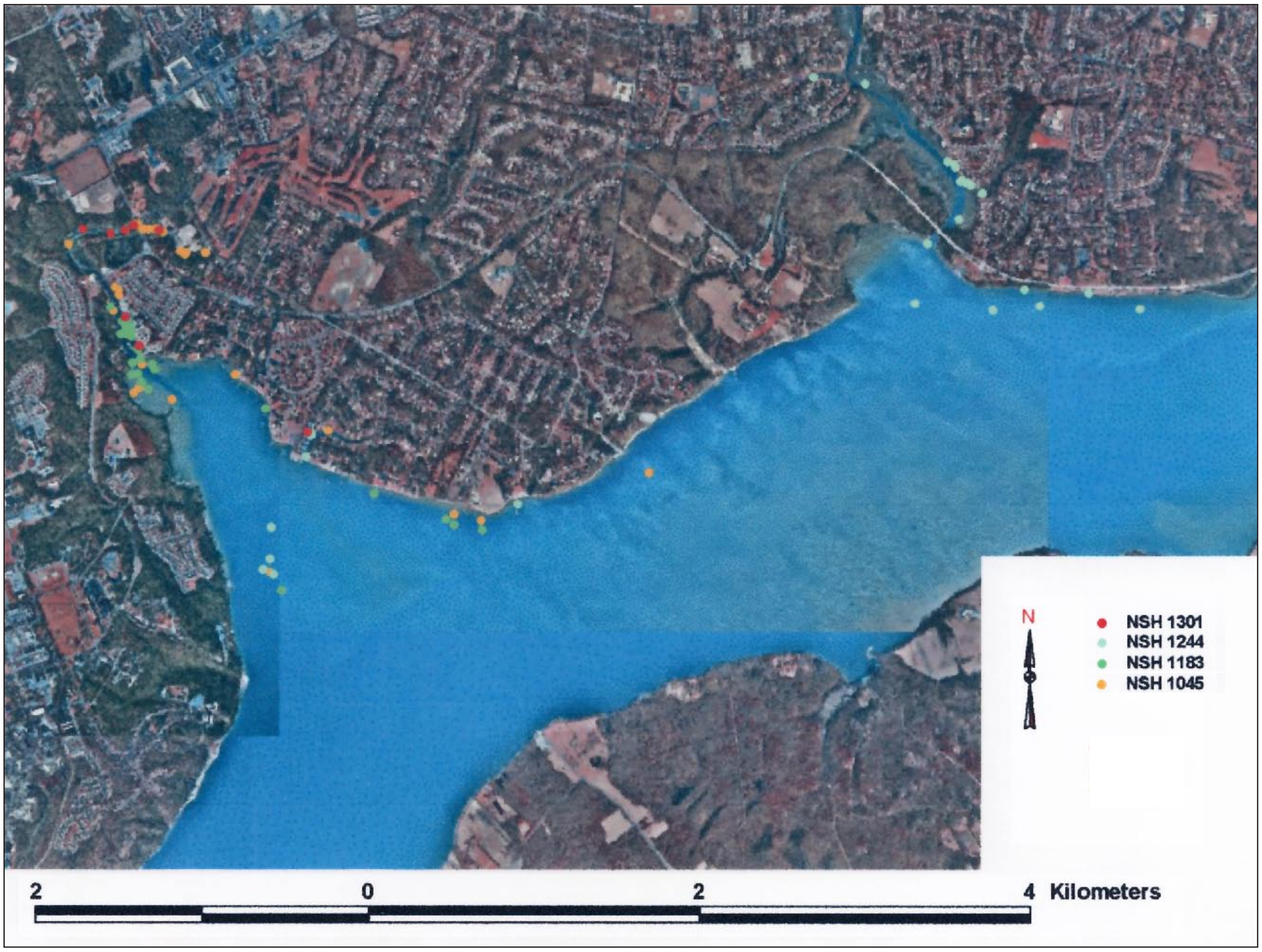

Figure 3. Northern snakehead movement for fish frequently contacted during the spawn (tag deployment–8 September 2006) and post spawn (15 September–4 January 2007) periods. Colored dots correspond to specific frequencies.

Northern snakeheads showed a habitat preference for hydrilla (*Hydrilla verticillata*; 24.0%), floating docks (22.8%), and milfoil (*Myriophyllum spicatum*; 21.6%) during this study (Table 5). Habitat utilization was determined for the spawn and post spawn periods (Table 5). During the spawn, floating docks (29.3%), hydrilla (22.8%), and spatterdock (*Nuphar luteum macrophyllum*; 11.4%) were the most readily-used habitats. Post spawn evaluation showed habitat preference changed slightly to milfoil (64.1%), hydrilla (23.1%), and piers (7.7%). Regardless of the habitat types utilized during this study, snakeheads were found exclusively in water less than 1.2 m deep with most contacts made in water less than 0.6 m deep.

Discussion

Although our sample size was low and biases inherent with telemetry studies were present due to variable contacts among individuals, we feel our study represents a starting point for evaluating northern snakehead habitat use and behavior in the Potomac River system. Radio tagged northern snakeheads that we were able to track exhibited limited movement throughout the study area, particularly during the spawning period. Most fish with which we had regular contact remained within Dogue Creek for the duration of the study; however, missing fish may have emigrated long distances beyond our search area. Northern snakehead populations have been reported across a wide temperature range (0 C to >30 C) in association with mud substrate and aquatic vegetation, and spawning generally occurs June–August in the Northern Hemisphere (Courtenay and Williams 2004). This corresponds to findings in the Potomac River (Odenkirk and Owens 2005, Odenkirk and Owens 2007). Channids, in general, construct nests within heavily vegetated areas by clearing a circular area from the bottom to the surface, and resulting nest design may aid in parental care of the young after hatching (Courtenay and Williams 2004). Studies in Asia have shown snakeheads prefer shallow ponds, canals, lakes, and rivers with mud substrate and aquatic vegetation (Courtenay and Williams 2004). Northern snakeheads in the Potomac system preferred shallow habitats with floating docks, hydrilla, milfoil, and spatterdock throughout the study. Habitat use during the spawn and post-spawn periods was associated with dense aquatic vegetation or structures that provided overhead cover. Although we failed to locate any nests during 2006, about 500 snakehead fry were collected in a heavily vegetated area on 7 September 2006 indicating a nest in close proximity of the capture site (Odenkirk and Owens 2007). During spring and early summer, snakeheads were usually found around floating docks and spatterdock beds, as hydrilla and milfoil were less abundant or even absent. Northern snakeheads are obligate air breathers and must periodically surface (Okada 1960). Consequently, it is possible that avian predators such as herons, eagles, and ospreys forage on northern snakeheads in the Potomac system. Numerous specimens were collected while electrofishing exhibiting wounds attributed to birds, and a photograph was provided by military personnel at Fort Belvoir documenting snakehead predation by ospreys near Dogue Creek. Increasing abundance of aquatic vegetation throughout the growing season along with increasing numbers of avian predators throughout the summer (Watts et al. 2001) may explain the extensive use of overhead cover throughout the year. Additionally, preference for a primary prey item (banded killifish, *Fundulus diaphanus*) closely associated with aquatic vegetation has been documented (Odenkirk and Owens 2007).

Core ranges during the spawn were considerably smaller than post-spawn. Similarly, home ranges documented during the spawn were almost seven times smaller than post-spawn. An increase in post-spawn activity may have been related to declining parental care. Eggs may be guarded by both parents for about two days before hatching, and newly hatched larvae remain in the nest and are guarded until the yolk is reabsorbed (Courtenay and Williams 2004). It has been reported that northern snakeheads have spawned as many as five times annually in the Amur River basin (Berg 1965), and it appears that spawning occurred over at least a five-month period, which may signal repeat spawns, within the Potomac River system (Odenkirk and Owens 2007).

Movement up and down river was primarily limited to the Virginia side of the Potomac. Channel depths ranging 9–15 m may have acted as a barrier to snakehead migration, as only one radio-tagged fish was documented on the Maryland shoreline during this study. Movement was limited between adjacent tributaries of Dogue Creek including Little Hunting Creek (to the north) and Pohick Bay (to the south). It appeared that although migration did occur on several occasions outside of Dogue Creek, fish that left quickly set up core ranges in new locations. Fish were documented migrating from Dogue Creek to Little Hunting Creek and then returning to Dogue Creek. Similarly, fish migrated to Pohick Bay and returned to Dogue Creek. Limited movement during our study may explain the relatively slow expansion of this newly established northern snakehead population.

Seasonal migrations have been linked to spawning, seasonal changes in water temperature, and habitat conditions for other species of fish (Bain et al. 1990, Clapp et al. 1990, Firehammer and Scarnecchia 2006), and similar patterns likely exist for northern snakeheads. Northern snakehead migration to decaying milfoil flats at the mouth of Dogue Creek near the edge of the Potomac River channel occurred in winter. It remains unclear as to potential cues that may have influenced this movement, but one scenario includes a response to the senescence of hydrilla in shallower waters. Relatively minor movement by northern snakeheads tracked within our survey area suggested contentment within occupied habitats. However, missing fish may have emigrated from the survey area and colonized unsampled areas upstream or downstream outside of our survey area. Research will continue to document population expansion and habitat utilization of this non-native piscivore into the foreseeable future. It is recommended that future telemetry studies of northern snakeheads include a 24-h tracking component to better estimate the movement through continuous tracking cycles (Rogers and White 2007), a larger sample size, and more intensive efforts to locate missing fish. Additionally, further research should include a comprehensive food habits study spanning all seasons, and estimates of growth rates, and interspecific competition.

Acknowledgments

Funding for this project was provided through Federal Aid in Sport Restoration grant F-111-R. Special thanks to VDGIF biologists, game wardens, and technicians who assisted in field collections and telemetry monitoring. George Palmer and John Kauffman provided helpful reviews.

Literature Cited

Anderson, W. G., R. S. McKinley, and M. Colavecchia. 1997. The use of clove oil as anesthetic for rainbow trout and its effects on swimming performance. North American Journal of Fisheries Management 17:301–307.

Bain, M.B., D.H. Webb, M.D. Tangedal, and L.N. Mangum. 1990. Movements and habitat use by grass carp in a large mainstream reservoir. Transactions of the American Fisheries Society 119:553–561.

Berg, L. S. 1965. Freshwater fishes of the USSR and adjacent countries, Vol III (4th ed., improved and augmented): [Translated from Russian; original 1949, Jerusalem, Israel, Program for Scientific Translations], pp. 937–1381.

Bettinger, J.M, and P.W. Bettoli. 2002. Fate, dispersal, and persistence of recently stocked and resident rainbow trout in a Tennessee tailwater. North American Journal of Fisheries Management 22:425–432.

Clapp, D. F., R. D. Clark, Jr., and J. S. Diana. 1990. Range, activity, and habitat of large, free-ranging brown trout in a Michigan stream. Transactions of the American Fisheries Society 119:1022–1034.

Courtenay, W. R., Jr., and J. D. Williams. 2004. Snakeheads (Pisces, Channidae): a biological synopsis and risk assessment. U. S. Geological Survey Circular 1251.

Daugherty, D. J. and T. M. Sutton. 2005. Seasonal movement patterns, habitat use, and home range of flathead catfish in the lower St. Joseph River, Michigan. North American Journal of Fisheries Management 25:256–269.

Firehammer, J. A. and D. L. Scarnecchia. 2006. Spring migratory movements by paddlefish in natural and regulated river segments of the Missouri and Yellowstone Rivers, North Dakota and Montana. Transactions of the American Fisheries Society 135:200–217.

Hart, L. G. and R. C. Summerfelt. 1975. Surgical procedures for implanting ultrasonic transmitters into flathead catfish (*Pylodictis olivaris*). Transactions of the American Fisheries Society 104:56–59.

Markham, J. L., D. T. Cosden, and R. K. Schaefer. 2002. Use of GIS generated habitat maps for sampling largemouth bass in Maryland's tidal rivers. American Fisheries Society Symposium 31:593–601.

Mortensen, D. C. 1990. Use of staple sutures to close surgical incisions for transmitter implants. American Fisheries Society Symposium 7:380–383.

Odenkirk, J. and S. Owens. 2005. Northern snakeheads in the tidal Potomac River system. Transactions of the American Fisheries Society 134:1605–1609.

——— and ———. 2007. Expansion of a northern snakehead population in the Potomac River system. Transactions of the American Fisheries Society 136:1633–1639.

Okada, Y., 1960. Studies of the freshwater fishes of Japan, II. Special part: Prefectural University of Mie, Journal of the Faculty of Fisheries, (4) 3:1–860, 61 plates.

Palmer, G. C., B. R. Murphy, and E. M. Hallerman. 2005. Movements of walleyes in Claytor Lake and the upper New River, Virginia, indicate distinct lake and river populations. North American Journal of Fisheries Management 25:1448–1455.

Popoff, N. D. and R. M. Neumann. 2005. Range and movement of resident holdover and hatchery brown trout tagged with radio transmitters in the Farmington River, Connecticut. North American Journal of Fisheries Management 25:413–422.

Rogers, K.B. and G.C. White. 2007. Analysis of movement and habitat use from telemetry data. Pages 625–676 *in* C.S. Guy and M.L. Brown, editors. Analysis and interpretation of freshwater fisheries data. American Fisheries Society, Bethesda, Maryland.

Watts, B., M. Byrd, and K. Cline. 2001. The bald eagle in Virginia: a management guide for landowners. The Center for Conservation Biology, College of William and Mary, Williamsburg, Virginia.

Winter, J. D. 1996. Advances in underwater biotelemetry. Pages 555–590 *in* B. R. Murphy and D. W. Willis, editors. Fisheries Techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Worton, B. J. 1989. Kernal methods for estimating the utilization distribution in home-range studies. Ecology 70:164–168.