

HOODED WARBLER HABITAT USE IN THE DELAWARE WATER GAP NATIONAL
RECREATION AREA AND AN ASSOCIATION WITH JAPANESE BARBERRY

By

Brandon W. Swayser, B.S.

Delaware Valley University

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APPROVAL PAGE

This thesis by Brandon W. Swayser submitted to the Office of Graduate and Extended Studies in partial fulfillment of the degree Master of Science in Biology on December 1, 2017 has been examined by the following faculty and it meets or exceeds the standards required for graduation as testified by our signatures below.

Terry L. Master, Ph.D., Thesis Chairperson

Date

Thomas C. LaDuke, Ph.D., Thesis Committee Member

Date

Howard P. Whidden, Ph.D., Thesis Committee Member

Date

Gregory George, Ph.D., Thesis Committee Member

Date

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University of Pennsylvania

Student's Name: Brandon W. Swayser

Title: Hooded Warbler Habitat Use in the Delaware Water Gap National Recreation Area
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Date of Graduation: December 16, 2017

Thesis Chair: Terry L. Master, Ph.D.

Thesis Member: Thomas C. LaDuke, Ph.D.

Thesis Member: Howard P. Whidden, Ph.D.

Thesis Member: Gregory George, Ph.D.

Abstract

Relatively recently Hooded Warblers (*Setophaga citrina*) have become abundant in the Delaware Water Gap National Recreation Area. Point counts conducted between 2011 and 2012 revealed that most Hooded Warbler detections occurred in areas dominated by the exotic invasive shrub Japanese Barberry (*Berberis thunbergii*). The objective of this study was to confirm that Hooded Warblers utilize thickets of this shrub as a breeding habitat and to further explain the relationship between these two species. Occurrence of Hooded Warbler territories was found to be significantly higher in areas containing substantial amounts of Japanese Barberry than in areas dominated by native understory plants. Hooded Warblers were also found to be older and occupy larger territories in Japanese Barberry areas. Vegetation structure and composition was analyzed to determine differences between Japanese Barberry and native understory-dominated territories, and compared to random available habitat. Several differences in vegetation structure and composition were observed. Ultimately, adequate data was attained to confirm that Hooded Warblers prefer to breed in Japanese Barberry in the National Recreation Area, a nesting preference previously not analyzed by researchers.

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CHAPTER I

Introduction

Exotic Invasive Species

An invasive species is defined as a species, which due to human activity, reproduces rapidly at the expense of native species (Hunter and Gibbs 2007).

Traditionally, an invasive species had been defined as any species that is non-native to a geographical area and causes harm, and this definition is still often used today (NWF 2017). However, a more modern viewpoint recognizes that native species can also become invasive in an area, due to human activities, to the point that they harm other native species. The White-tailed Deer (*Odocoileus virginianus*) is considered to be invasive in its native range by many ecologists since the species has become so overpopulated (due to human eradication of its predators and creation of more of its preferred forest-edge habitat) that it destroys understory habitat that many other native species rely on. Such over-browsing of native shrubs and saplings by White-tailed

Deer has been shown to suppress native forest regeneration (Aronson and Handel 2011).

An exotic species is defined as any species introduced by humans, accidentally or purposefully, to an area outside of its native range. Only a very small subset of these exotic species become established in an area and even fewer of these become invasive species (Williamson and Fitter 1996). Many synonyms exist for exotic species including introduced species, alien species, non-indigenous species, and non-native species.

Japanese Barberry (*B. thunbergii*) is a plant that has been introduced into much of the eastern United States and has become a prolific and destructive exotic invasive species.

There is concern in the Delaware Water Gap National Recreation Area of northeastern Pennsylvania and northwestern New Jersey that Japanese Barberry is invading open niches created by over-browsing of native understory shrubs and saplings by White-tailed Deer. This barberry species outcompetes native plants for resources and displaces native plant species. This invasion has dire consequences for animal species that depend on native plants for food, nesting, and shelter. Despite its undeniably negative impact, Japanese Barberry may be preferred by Hooded Warblers (*S. citrina*, formerly *Wilsonia citrina*) and other shrub-nesting bird species as a breeding habitat, presumably due to nest protection provided by its dense spiny structure. Eradication of this plant is encouraged but nearly impossible due to constant dispersal of its seeds by birds and other wildlife. Since it seems doubtful that Japanese Barberry will ever be fully eradicated or controlled, documenting any potential benefit to native

wildlife provided by this plant, and developing a greater understanding of the relationship between it and Hooded Warblers may be valuable to avian conservation, and is the primary objective of this study. This study will also serve to advance earlier research done on this topic by Kutch (2013).

Hooded Warbler (*Setophaga citrina*)

Taxonomy

The Hooded Warbler (hereafter HOWA) is a small Neotropical migrant in the family Parulidae. Members of the taxonomic family Parulidae are classically referred to as the “American Wood Warblers”. Parulidae consists of 116 species, however, taxonomy within this family is not completely resolved, and various sources place between 114 and 118 species in this family, with 57 of these species occurring in North America (Curson et al. 1994). Hooded Warblers were traditionally placed in genus *Wilsonia*, until 2010 when this and 24 other North American species were moved to the genus *Setophaga* based on mitochondrial DNA analysis (Lovette et al. 2010). The systematics of 23 warbler genera were revised to better fit this new evidence. The aforementioned 25 species were found to be of a common clade based on this molecular evidence, and this clade was assigned the genus name *Setophaga* after its earliest described species, the American Redstart (*S. ruticilla*) (Lovette et al. 2010). No subspecies within *S. citrina* have been described.

Morphology

Hooded Warblers average 13 cm in length with a body mass of approximately 11 grams (Chiver et al. 2011). Hooded Warbler plumage is olive-green on the back and wings and bright yellow on the head and underparts. The outer three flight feathers on either side of the tail (rectrices 6, 5, and 4) have white medial edges and olive-green lateral edges, with the inner tail feathers (rectrices 1, 2, and 3) being entirely olive-green.

The species is generally sexually dimorphic in plumage with males showing a distinct bold black hood that covers the crown, nape, throat, chin, and sides of the neck, with the lores, supercilium, auriculars, and malar area remaining bright yellow (Fig. 1). Young males have a less extensive hood than older males with yellow edging on many of the black hood feathers. This hood becomes more extensive and more completely black with age. Young females typically lack a hood and show entirely yellow heads, but gain black in the periphery or margins of the hood region that becomes more extensive with age. Very old females can strongly resemble males (Pyle 2001) (Fig. 26, App. XI).



Figure 1. Female HOWA (left) and male HOWA (right), showing typical plumage aspects of each sex. Photographs from May, 2016, by B. Swayser.

Hooded Warblers have dark brown irises, and black to grayish-black bills and gapes. Their legs are a light flesh color, with feet being similarly colored but slightly darker (Chiver et al. 2011). Male HOWA average larger than females and ASY birds (birds beyond their second calendar year of life) average larger than SY birds (birds in their first breeding season/second calendar year of life). Male wing chord measurements range from 63-71 mm and rectrix measurements range from 50-59 mm. Female wing chords range from 58-67 mm while rectrix length ranges from 47-56 mm (Pyle 2001). HOWA have sensory bristles around the gape to aid in fly-catching and gleaning of prey items.

Natural History

Geographic Distribution: HOWA have a breeding range that extends north from southeastern Iowa to the southern great lakes region and southern Ontario. Their breeding range extends southward to southeast Texas, the Gulf of Mexico coast, and northern Florida, westward to eastern Texas, western Arkansas, eastern Missouri, and western Illinois, and eastward to the Atlantic coast (James et al. 1976) (Fig. 2). Research indicates that HOWA distribution has expanded northward approximately 115 km (71 mi) during a 26-year period between two U.S. Breeding Bird Surveys (1971-1997) (Hitch and Leberg 2007). U.S. breeding bird survey data shows a decline in HOWA populations in the southern extreme of their range (Fig. 9), and this, coupled with the northward expansion, may indicate a range shift northward, as is typical of many species due to climate change (Sauer et al. 2017, Visser 2008). Core wintering distribution ranges from southern Mexico through Central America as far south as Panama along the Atlantic/Gulf coast. Smaller regular wintering populations also exist in the Caribbean Sea on the islands of Bermuda, Cuba, Puerto Rico, the British Virgin Islands, and several

islands of the Lesser Antilles (Arendt 1992). Wintering populations exist on the Pacific coast and inland in western Mexico but are less common (Chiver et al. 2011) (see Fig. 2).

HOWA perform a complete migration, migrating nocturnally, typically through or over deciduous and mixed forests (Chiver et al. 2011). Like most passerines, they likely use a combination of landmarks, celestial cues, geomagnetism, solar position, and

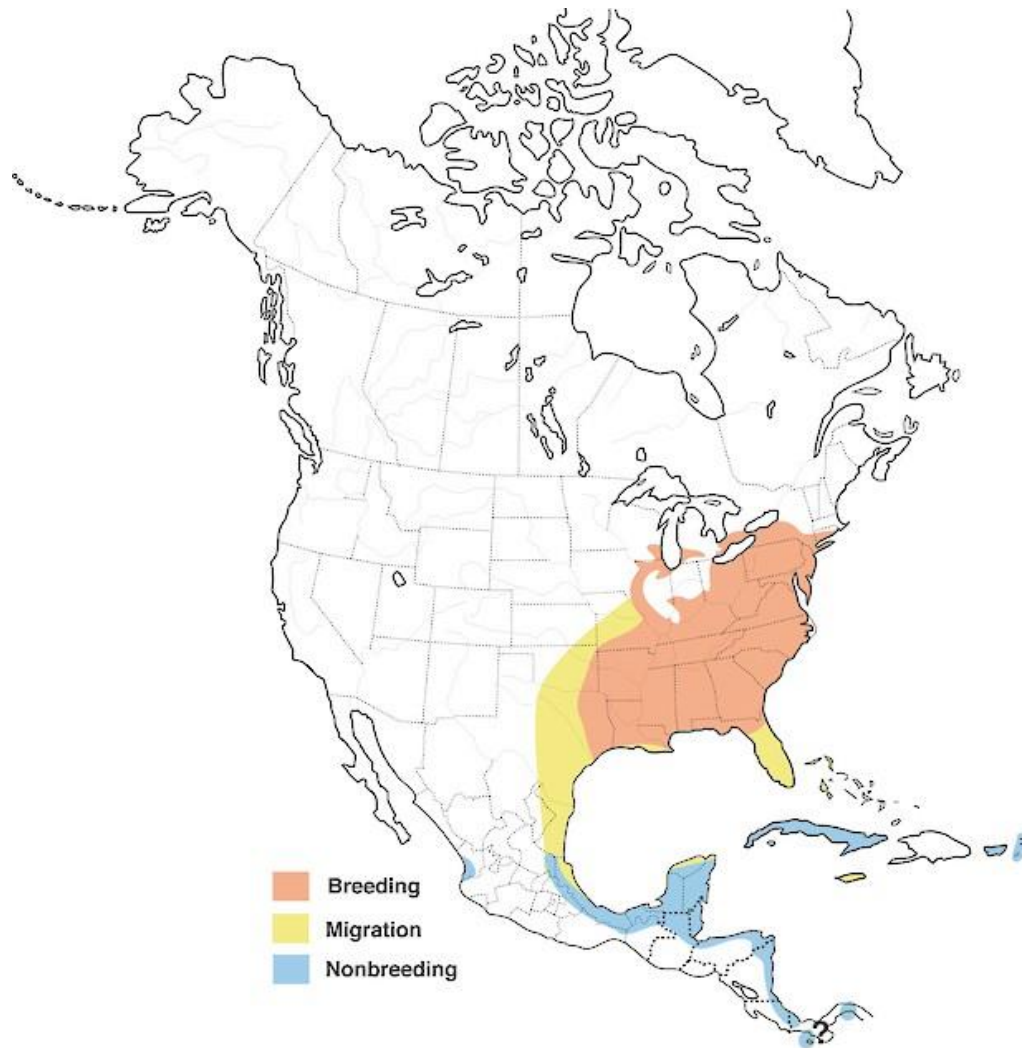


Figure 2. Range map of Hooded Warbler (*Setophaga citrina*) (Chiver et al. 2011). Macaulay Library at the Cornell Lab of Ornithology.

skylight polarization to navigate (Åkesson and Hedenström 2007). HOWA leave summer breeding grounds in the U.S. and Canada from late July to late September and fly at night over several weeks until they reach their wintering destination in late August to late October. HOWA depart wintering grounds from early to mid-March and arrive on breeding grounds from late March through mid-May depending upon latitude. Some populations migrate along the western coast of the Gulf of Mexico in the fall, but fly directly across the Gulf in the spring (Chiver et al. 2011).

In Pennsylvania, HOWA are mostly distributed in the western third of the state, particularly on the Allegheny Plateau. Fewer populations exist in southeastern Pennsylvania or southern New Jersey (Stutchbury 2012, Wilson et al. 2012). Although HOWA were once uncommon in northeastern Pennsylvania and northwestern New Jersey, the distribution and density of this species has increased in recent years, and HOWA can now be found commonly in the Pocono Mountains and vicinity as well as further south along ridges of the Appalachian Mountains (Fig. 3, 10).

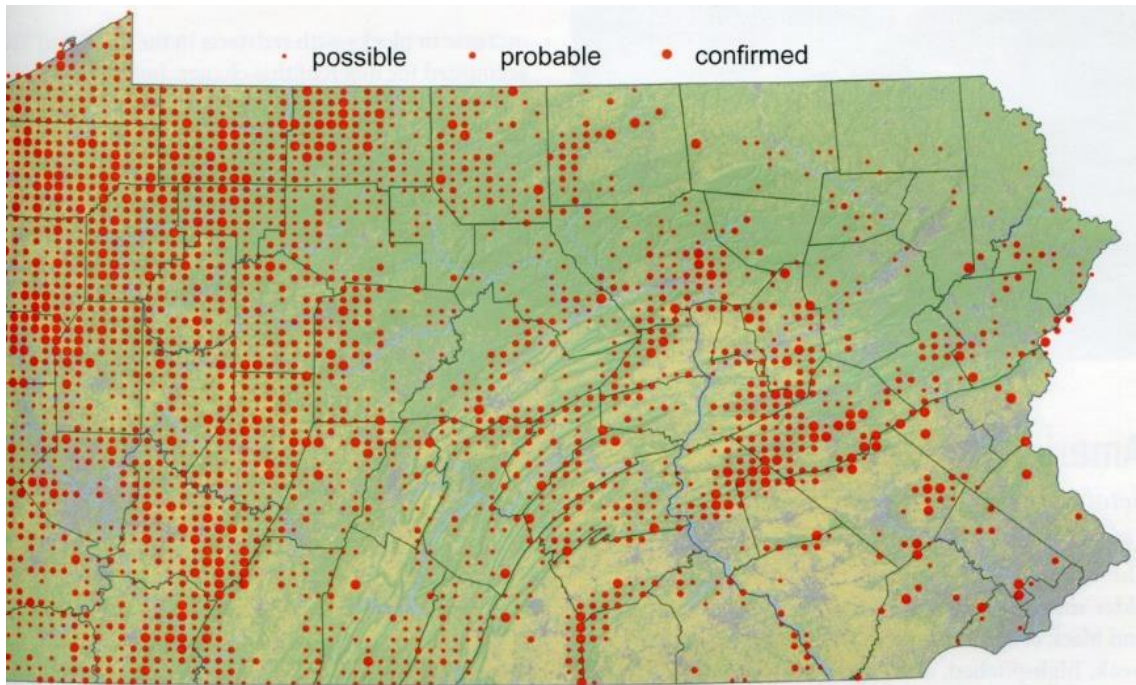


Figure 3. Pennsylvania Breeding Bird Atlas results showing distribution of HOWA as of 2009 (Wilson et al. 2012).

Habitat Preference: In their breeding range, Hooded Warblers prefer low elevation, mature deciduous or mixed forest. When nesting, they require a dense shrub-dominated understory, although they will also utilize dense saplings (Chiver et al. 2011, Stutchbury pers. comm. 2017). In their northern breeding range, HOWA inhabit hardwood forest dominated by Sugar Maple (*Acer saccharum*), American Beech (*Fagus grandifolia*), Black Cherry (*Prunus serotina*), and Eastern Hemlock (*Tsuga canadensis*). These habitats contain understory vegetation typically dominated by *Rubus* spp. shrubs, Prickly Gooseberry (*Ribes cynosbati*), Maple-leaf Viburnum (*Viburnum acerifolium*), Spicebush (*Lindera benzoin*), and saplings of Ash (*Fraxinus* spp.), American Beech, Cherry (*Prunus* spp.), and Maple (*Acer* spp.) (Chiver et al. 2011).

In the southern part of their breeding range HOWA prefer wooded, swampy bottomland hardwood forests dominated by Bald Cypress (*Taxodium distichum*), Tupelo/Black Gum (*Nyssa sylvatica*), Red Maple (*Acer rubrum*), and Sweetgum (*Liquidambar styraciflua*) (Howlett and Stutchbury 1996, Kilgo et al. 1996). Hooded Warblers prefer to nest in areas near forest edges or open gaps in the canopy, likely because the dense understory preferred for nesting is more developed below canopy gaps and along edges due to increased sunlight penetration. These gaps or holes in the canopy are often created by fallen trees or by human disturbance such as logging. HOWA utilize understory shrubs and saplings for nesting, and the canopy for feeding, while mid-story is used less often (Chiver et al. 2011).

In the Delaware Water Gap National Recreation Area, HOWA inhabit moist wooded ravines in the Delaware River valley. Canopy tree species that dominate HOWA territories include Sugar Maple, Black/Sweet Birch (*Betula lenta*), and several Oak species (*Quercus* spp.). Dominant shrub species in these territories include Japanese Barberry, Blueberry (*Vaccinium* spp.), and Spicebush.

In their winter range, HOWA display different habitat preferences and social structure. HOWA exhibit marked sexual segregation on wintering grounds, with males dominating habitats within mature forest that contain optimal food resources, while females reside in more arid habitats dominated by late-successional shrubs or scrubby fields (Stutchbury 1994). Research has shown that when males are experimentally removed from these habitats, females do not always claim the vacant territories. Hatch-

year males that otherwise act as “floaters” without established territories within the scrub habitat, will relocate into territories vacated by removed males. Lynch et al. (1985) found that the few females inhabiting male-dominated forest habitats typically had more melanistic, male-like facial plumage. However, Stutchbury (1994) showed no correlation of female coloration with mature forest territory occupancy. Regardless, the two studies hypothesized that segregation by habitat likely reduces intraspecific competition amongst HOWA in their winter range.

Diet/Foraging Ecology: Hooded Warblers are primarily insectivorous on both wintering and breeding grounds. Invertebrates regularly taken include small spiders, lepidopterans (butterflies and moths, especially larvae on breeding grounds), coleopterans (small beetles), dipterans (small flies), and orthopterans (small grasshoppers, tree crickets etc.). Many other arthropods have been recorded as food items as well. Moorman et al. (2007) showed that HOWA have a preference for weevils (and other beetles), and lepidopterans (caterpillars and adults) relative to the abundance of these prey items in foraging habitats. Quantitative analysis of stomach contents on wintering grounds showed a preference for weevils, fungus beetles, bark beetles, and hymenopterans (ants and wasps) (Rappole and Warner 1980). A study analyzing diet over four temporal periods (spring migration, fall migration, breeding, and post-breeding) found no significant temporal difference in diet items (Moorman et al. 2007). Hooded Warblers drink very infrequently and likely fulfil their water intake

needs from the insects they eat. Nutritional needs, energetics, and metabolism have not been studied in this species (Chiver et al. 2011).

Food is primarily captured by hawking or aerial flycatching of insects, as well as by gleaning arthropods off of leaf surfaces, although other foraging methods have been observed (Bennett 1980). Hawking of insects is the most commonly used food capture method on wintering grounds, while gleaning from leaves and/or stems is the most commonly used method on breeding grounds (Kilgo 2005). Chen et al. (2011) found that HOWA tend to fly more when feeding than other parulids.

On wintering grounds foraging habitat is comprised of sapling foliage, low shrubs, and ground cover, with low shrubbery dominating the foraging zone (Keast 1980). As stated above, males and females occupy different habitats on wintering grounds, however they do not differ in foraging behavior or in the general height of preferred foraging zones. Winter foraging height is typically below one meter (Keast 1980, Morton et al. 1987). Edge habitat near disturbed areas of forest is preferred during spring and fall migrations (Bowen et al. 2007). On breeding grounds, foraging is done in both contiguous forest and in canopy gaps and edges (Chiver et al. 2011). Foraging on breeding grounds typically occurs in the canopy at heights of 10-18 meters, or in dense low shrubbery (Bennett 1980). Foraging rates were observed to be higher in contiguous forest than in gaps when adults foraged alone, but equal in gaps and away from gaps when adults were foraging to feed fledglings (Kilgo 2005)

Phenology: Males arrive on Pennsylvania breeding territories in late April to early May, with females arriving a few days later. Females select males by song quality, form pairs, and settle on territories within several days of their arrival (between May 7 and June 4 in Pennsylvania) (Chiver et al. 2011). Females select the nest location and begin constructing nests, a process that lasts 2-6 days. Dates for first egg laid range from May 11 to June 10, with older (ASY) females arriving and laying earlier than yearling (SY) females. Incubation lasts for 12-14 days. Young fledge 8-9 days after hatching, and the male assumes care of the young until they are independent in 4-5 weeks. If second broods are attempted, this occurs between June 31 and July 19 (Chiver et al. 2011). Less than half of females attempt second broods when nests are not predated, but females will typically re-nest if first attempts are predated (Chiver et al. 2011). HOWA depart breeding grounds from late July to late September and arrive on wintering grounds from late August to early November (Chiver et al. 2011). Northward departure from wintering grounds begins in early March (Ramos 1986). Both males and females attempt to breed in their first breeding season after hatching, and age at first breeding is 10-11 months (Chiver et al. 2011).

Breeding Behavior: Males choose territories and defend them aggressively against other HOWA, assuming most of the territory defense responsibilities for the pair. Females are solely responsible for nest construction, incubation, and brooding. Both parents feed nestlings and remove fecal sacs from nests, with females often consuming them (Chiver et al. 2011). Males more commonly look after fledglings,

especially when the female is attempting a second brood. Females will chip aggressively when predators approach nests and have been observed performing a broken-wing display in attempts to distract predators and lure them away from the nest (Stutchbury pers. comm. 2017)

Nesting: Nests are typically placed 0.3 to 1.4 m high in dense patches of shrubs near forest edges or canopy gaps (Howlett and Stutchbury 1996) (Fig. 4). Two or more vertically or obliquely branching stems of plants are usually incorporated as nest supports, and leaves are sometimes used to conceal nests. In one study, an average of 64 cm of dead leaves were found to hang from below nests, and 47 percent of nests



Figure 4. Typical HOWA nest placement; low to the ground and in dense understory. Photograph taken by Richard Bonnett on May 29, 2009. Macaulay Library at the Cornell Lab of Ornithology (Bonnett 2009).

were visible from one meter (Howlett and Stutchbury 1996). Across their range, HOWA universally choose very dense and often thorny or spiny shrubs/saplings regardless of female age (Howlett and Stutchbury 1997) (see Fig. 4).

Common native plants used as nest substrate in northern portions of HOWA range include Blackberry (*Rubus allegheniensis*), Northern Dewberry (*Rubus flagellaris*) American Beech saplings, Black Cherry saplings, and Prickly Gooseberry (Chiver et al. 2011). In southern areas, River Cane (*Arundinaria gigantea*), Red Bay (*Persea borbonia*), Common Gallberry (*Ilex glabra*), American Holly (*I. opaca*), Water Oak (*Quercus nigra*), and blueberry are often used as nesting substrate (Kilgo et al. 1996). Exotic invasive shrubs such as Multiflora Rose (*Rosa multiflora*) and Japanese Barberry are used as nest



Figure 5. Typical HOWA nest, from Augusta, Richmond Co., Georgia. Ruler is in cm. Photograph taken by Rene Corado on May 31. Macaulay Library at the Cornell Lab of Ornithology (Corado May 31).

substrate where their ranges and HOWA range overlap (Schlossberg and King 2010, Garrett 2015).

Only females build nests, creating a cup nest over the course of 2-6 days. Nest construction is completed throughout the day with the majority of work being done in the early morning (Chiver et al. 2011). The nest is an open cup made of woven plant materials including soft inner bark, plant down, and fine grasses, and often reinforced with spider web (Bent 1953) (Fig. 5). Average dimensions of HOWA nests are 70-85 mm outside diameter, 60-70 mm inside diameter, and 30-50 mm in depth (Chiver et al. 2011). Females do not actively maintain nests after the onset of incubation, and females do not repair damaged or tipped nests. Nests are not reused in subsequent years (Chiver et al. 2011).



Figure 6. HOWA nest from above with an incomplete clutch of three eggs, taken May 23, 2017 in block three. Photograph by B. Swayser.

Eggs are ovate, approximately 18 mm long, 14 mm wide, approximately two grams in mass, and are creamy white in color with brown markings concentrated at the wider end of the egg (Chiver et al. 2011) (Fig. 6).

Females lay their first egg after the nest is lined, laying one egg in the early morning on consecutive days until the clutch is complete. Typically, four eggs are laid, with a 12 day incubation period beginning after the final egg is laid (Chapman 1907, Chiver et al. 2011). Only females develop a ventral brood patch, and are solely responsible for incubation. In a study of clutch size, 2% of clutches had two eggs, 9% had three eggs, 80% had four eggs, and 9% of nests contained five eggs (Mark and Stutchbury 1994). Interestingly, nests initiated late in the season (July) all contained three eggs.

Chicks: Chicks hatch together over a period of two days, often between early morning and early afternoon (Chiver et al. 2011). Chicks are altricial and naked with eyes closed upon hatching. Chicks leave the nest as fully feathered fledglings 8-9 days after hatching, and can fly within 2-3 days of fledging. Chicks become independent within 4-5 weeks. When feeding chicks, each parent will feed half of the brood (Evans Ogden 1994). Immature siblings will often remain together until the end of the summer, with immature males sometimes establishing and singing on small territories in their first summer (Chiver et al. 2011).

Dispersal: Natal philopatry is very low in HOWA, with only 1-10 percent of dispersed young returning to the breeding grounds where they were hatched (Chiver et

al. 2011). Research suggests that immature birds may seek out breeding territories for future seasons after hatching, before their first southward migration (Chiver et al. 2011).

Site fidelity: Adults of this species have been known to show significant breeding site fidelity, with Pennsylvania males and females returning to breeding sites 52% and 43% of the time, respectively (Chiver et al. 2011). In a Pennsylvania study males showed a 58% rate of fidelity to breeding habitat types, and females a rate of 29% fidelity to breeding habitats (Howlett et al. 2003). Little research has been done on winter site fidelity, but Rappole and Warner (1980) found that six of 10 individuals returned to wintering territories.

Longevity and Survivorship: The oldest known individual survived eight years and one month (BBL 2016). Little research has been done concerning average HOWA longevity, but eight years is likely an outlier. Survivorship of adults on breeding grounds is very high, with 95% of males surviving the entirety of the breeding season in a Pennsylvania study (Rappole and Warner 1980). Survival of fledglings to independence is low, and has been measured at 19% in northwestern Pennsylvania (Rush and Stutchbury 2008).

Predation: Hooded Warblers have many nest predators including but not limited to Raccoons (*Procyon lotor*), Blue Jays (*Cyanocitta cristata*), American Crows (*Corvus brachyrhynchos*), Eastern Chipmunks (*Tamias striatus*), Red Squirrels (*Tamiasciurus hudsonicus*), Striped Skunks (*Mephitis mephitis*), Virginia Opossums (*Didelphis*

virginiana), and Black Rat Snakes (*Pantherophis alleghaniensis*) (Chiver et al. 2011)

White-Tailed Deer are also known to prey upon passerine nestlings, and may do so to HOWA (Pietz and Granfors 2000). Nest predation rates are extremely variable based on geographical region, but as with many passerines, are likely higher near edges and small fragments (Terborgh 1989). Brood parasitism by Brown-headed Cowbirds (*Molothrus ater*) is a major concern for HOWA. Little is known regarding predation of adults on breeding grounds, however, Ferruginous Pygmy Owls (*Glaucidium brasilianum*) and Vaillant's Frog (*Lithobates vaillanti*) have been known to prey upon adult HOWA on wintering grounds (Chiver et al. 2011).

Molt

Adult (second year or older) Hooded Warblers undergo a complete molt annually, replacing all body and flight feathers with fresh basic plumage feathers (Pyle 2001). This complete molt (termed prebasic) occurs on summer territories after breeding and before fall migration (mid-July to early August). Hatch year birds leave the nest with completely juvenile plumage and undergo a partial first prebasic molt before migrating. In this partial molt all body feathers, all secondary coverts (greater, lesser and median), and the proximal one or two alular feathers (but always excluding the greater alula) are replaced by formative plumage. The primary coverts, greater alula, and all flight feathers (primaries, secondaries, rectrices, and tertials) are retained until after the following breeding season. This partial first prebasic molt creates a molt limit

in the wings of first year birds, and allows them to be aged accurately until their next prebasic molt (Pyle 2001) (Fig. 25). Unlike many parulids, HOWA lack an alternate plumage or prealternate molt (Pyle 2001, Stephenson and Whittle 2013)

Vocalizations

Singing is mostly performed by males with only one record of female song (Evans Ogden et al. 2003). Singing is used for territory defense and to attract females, and counter-singing between neighboring males is common (Neudorf et al. 2008). Territories are established by singing and are vigorously defended from other males (Bielefeldt and Rosenfield 2001). Males utilize several song types, differentiated by frequency, number of notes, and range (Fig. 7) (Godard 1991, Wiley et al. 1994, Stephenson and Whittle 2013). Song types can be divided into one main “repeat mode

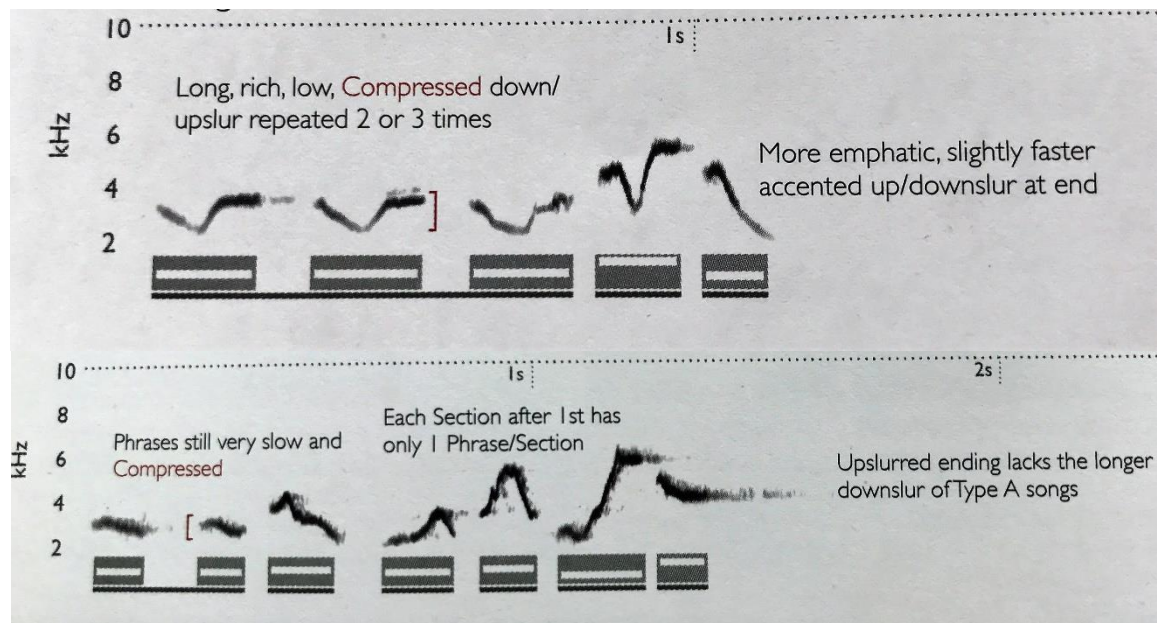


Figure 7. Sonograms of a typical repeat mode song (top) and a mixed mode song (bottom) (Stephenson and Whittle 2013).

song”, and 3-8 “mixed mode songs.” The repeat mode song is typically the most commonly used, and is recognized mnemonically as “*ta-wit ta-wit ta-wit tee-yo*” (Fig. 7). The repeat mode song is repeated 5-6 times per minute and is sung constantly prior to attracting a mate. About five percent of males sing an atypical song type in repeat mode. The other song types are used more irregularly, and sung 10-12 times per minute (termed “mixed mode”, “dawn song”, or “aggressive song”) (Chiver et al. 2011).

Males sing from spring arrival on breeding grounds until late summer before fall migration, with singing becoming less frequent in mid-summer. Singing does not occur on wintering grounds (Chiver et al. 2011). Males spend 50-60% of their time singing prior to mating, and singing is much decreased during incubation (by the female) and chick-rearing (Wiley et al. 1994). Males tend to sing mixed mode songs more on the edges of territories and just after sunrise. Males respond aggressively to other males’ songs, and to playbacks of HOWA songs within their territories, although response decreases during incubation. Each male has an individually distinctive song, and long term memory enables males to remember neighbors’ songs from year to year, which may reduce the costs of territorial defense (Godard 1991). Research indicates that females mated to males who sing at a lower rate are more likely to seek extra-pair copulations (Chiver et al. 2011).

Chip calls are used by both sexes, on both wintering and breeding grounds. On wintering grounds chip notes are used for territory defense (Chiver et al. 2011). The HOWA chip note is loud and metallic, reminiscent of a Northern Cardinal (*Cardinalis*

cardinalis), but “sweeter”. Although the structure of the chip note stays constant throughout the year, the function of the chip notes varies greatly by season. Both sexes chip regularly in the winter, however, males chip very infrequently on breeding grounds (Chiver et al. 2011). Frequent female chipping is likely used to advertise to males. On breeding grounds, females chip irregularly when in the fertile stage (nest building and egg-laying), with a rate of 18-21 chips per minute in several short bouts. Females chip much more regularly when incubating but off nest (32 chips per minute) for one or two long (10-12 minute) chipping bouts (Stutchbury 1998, Chiver et al. 2011). During aggressive interactions such as territory disputes and extra-pair copulation attempts, chip notes become rapid and repeated (Morton et al. 1987). Chip calls interspersed with a higher-pitched alarm call are used when predators and Brown-headed Cowbirds (*Molothrus ater*) are nearby.

Songs of Hooded Warblers are very different from those of other warblers, with the most similar being Magnolia Warbler (*Setophaga magnolia*). Magnolia Warbler song is similar to repeat mode HOWA song but faster, higher in frequency, and quieter (Chiver et al. 2011). Bill-snaps are the only non-vocal sounds used by HOWA and function in territorial defense and defense against predators (Rappole and Warner 1980).

Conservation and Management

Population Trends: In North America, Hooded Warbler populations have been increasing as a whole in recent years, as shown by the U.S. Breeding Bird Surveys conducted between 1966 and 2009 (Sauer et al. 2017) (Fig. 8, 9). As of 2015, nationwide populations have increased by 1.36% (Sauer et al. 2017). HOWA populations may be benefiting from small-scale habitat disturbances (such as selective logging and clearing roads or trails) that increase optimal forest edge/canopy gap nesting habitat (Bielefeldt and Rosenfield 2001, Chiver et al. 2011).

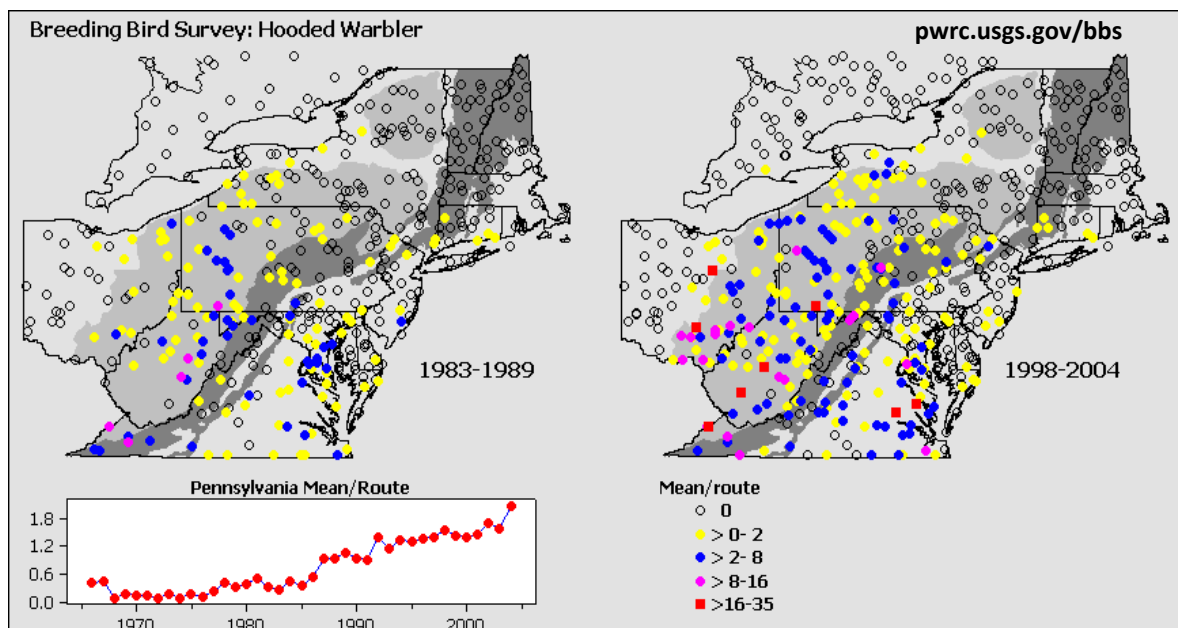


Figure 8. Map showing percent change in mean HOWA sightings per survey route during USGS breeding bird surveys between 1966 and 2009 in Pennsylvania and surrounding states (Sauer et al. 2017).

Although populations are increasing and/or stable throughout much of their range, HOWA are considered a threatened species in Canada. The country's HOWA distribution is restricted to one population in the Carolinian Forest of southern Ontario

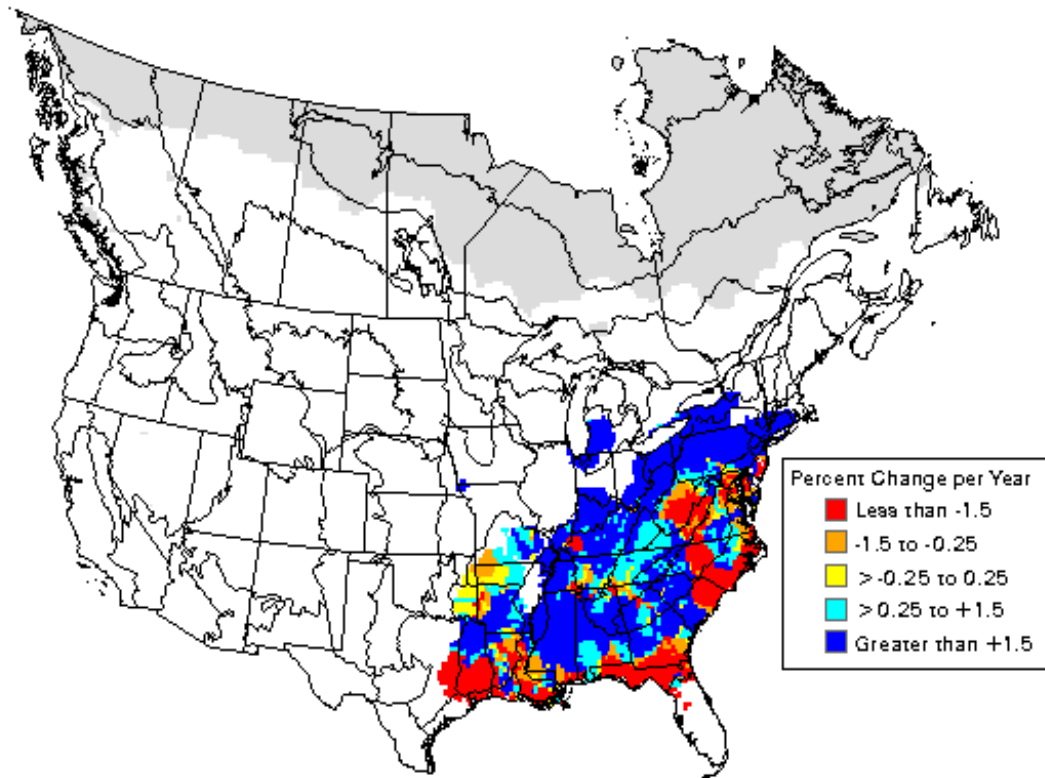


Figure 9. Map showing percent change in HOWA populations based on USGS BBS data between 1966 and 2009 across the entire breeding range of HOWA (Sauer et al. 2017).

due to fragmentation caused by agricultural activities and urban sprawl (Gartshore 1988, Chiver et al 2011). HOWA are sensitive to large-scale habitat loss and fragmentation as this increases competition for territories, and increases optimal habitat for Brown-headed Cowbirds, which leads to an increase in brood parasitism. Average HOWA territory size has been found to be 0.49 ha (1.2 acres) in contiguous forest, and 2.23 ha (5.5 acres) in forest fragments (Chiver et al. 2011). Likewise, nearest neighbor distances were 50-75 m in contiguous forest, and up to 600 m within fragments (Chiver et al. 2011). Due to edge effects, HOWA require more territory area in lower quality, fragmented habitat patches, thus increasing competition and decreasing the number of individuals that such habitat patches can support. In the

United States HOWA are listed as Threatened in the state of Wisconsin for similar reasons (Kreitinger 2017).

In New Jersey, breeding HOWA populations are concentrated in the northwestern and south-central regions of the state (Fig. 10). In Pennsylvania, HOWA breeding populations are concentrated in the western half of the state, on the Allegheny Plateau, with additional populations scattered throughout the Appalachian and Pocono Mountains (Fig. 11a). Pennsylvania

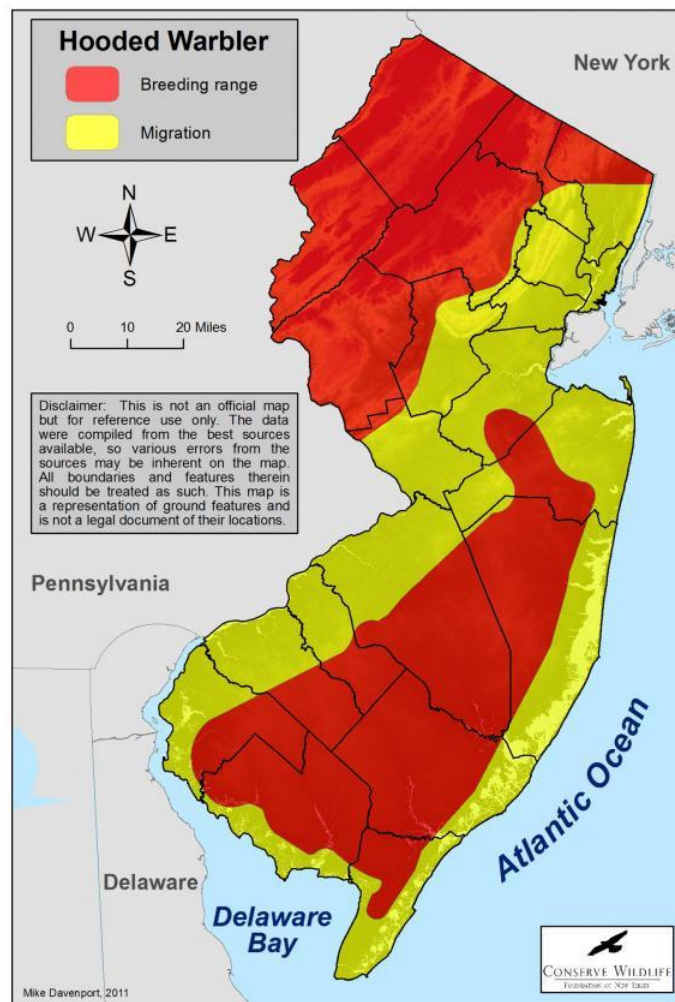


Figure 10. HOWA distribution in New Jersey (Davenport 2011).

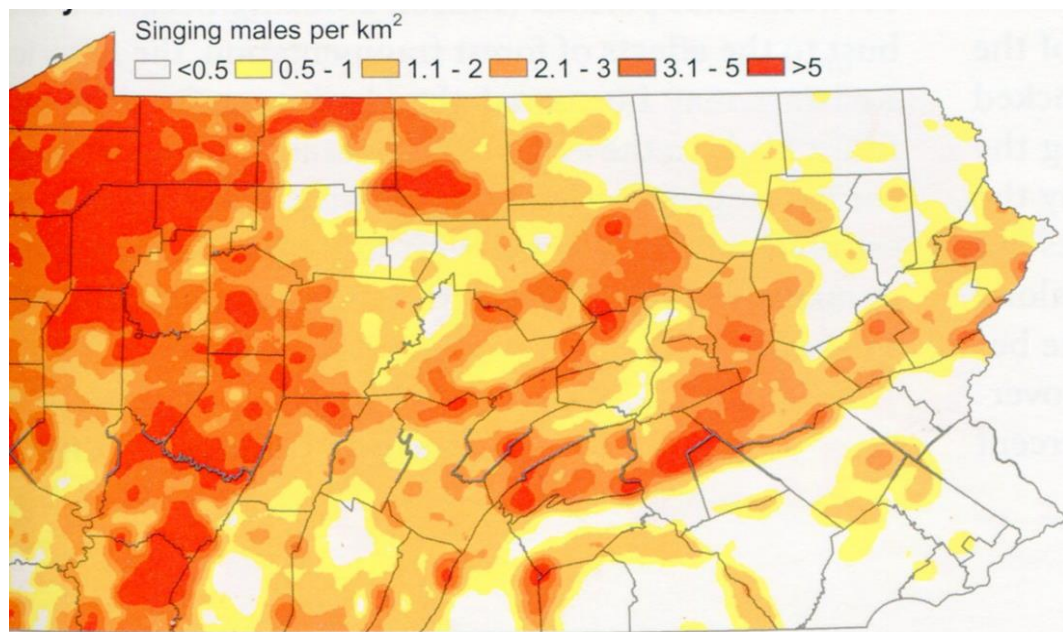


Figure 11a. PA Breeding Bird Atlas results showing density of HOWA between 2004 and 2009 (Wilson et al. 2012).

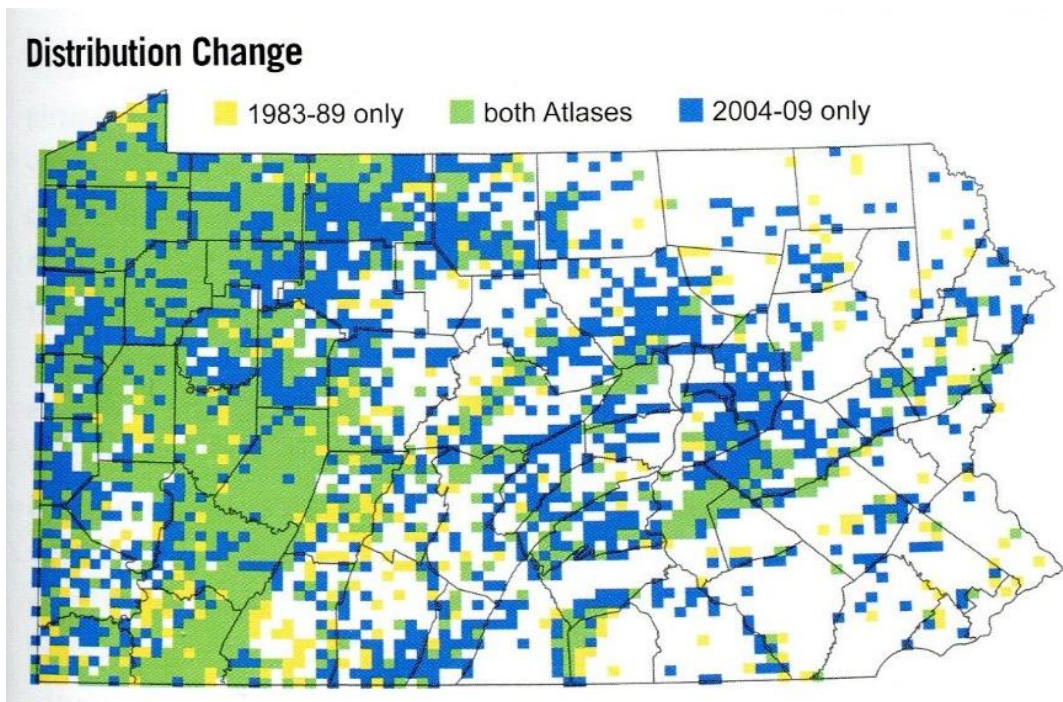


Figure 11b. PA Breeding Bird Atlas results showing change in distribution of HOWA from the 1983-1989 to the 2004-2009 survey periods (Wilson et al. 2012).

Breeding Bird Atlas showed a 25% overall increase in confirmed HOWA sightings between the 1983-1989 and 2004-2009 survey periods (Fig. 11b) (Wilson et al. 2012). In northeastern Pennsylvania and northwestern New Jersey, HOWA populations appear to be increasing, especially in the moist wooded ravines of the Delaware Water Gap National Recreation Area (Kutch 2013) (Fig. 11).

Brown-headed Cowbird: Passerine brood parasitism rates generally increase in smaller forest fragments and this seems to be the case with HOWA (Terborgh 1989). Brood parasitism by Brown-headed Cowbirds (*Molothrus ater*) (BHCO) is problematic for breeding Hooded Warblers as it reduces reproductive success (Stutchbury 1997). BHCO parasitism of HOWA varies geographically, being as high as 75% in Illinois and as low as 5% in Arkansas (Chiver et al. 2011). In Pennsylvania, parasitism rates were observed to be 62% (Stutchbury 1997). Historically, BHCO parasitism rates of HOWA were lower than current levels as HOWA nested more commonly in large interior forest tracts that were less accessible to BHCO and less preferred by BHCO than forest edges. As these tracts are split into smaller fragments by human development, HOWA nests are more likely to be parasitized due to increased BHCO accessibility, as shown experimentally in Pennsylvania (Rush and Stutchbury 2008). In South Carolina, HOWA nests near forest edges were much more likely to be parasitized than nests in the forest interior (Moorman et al. 2002).

HOWA are particularly vulnerable to parasitism as females do not reject or remove BHCO eggs and routinely incubate them with their own eggs. HOWA also do

not lay additional eggs to compensate for or replace those lost to parasitism. HOWA have been observed to abandon nests with BHCO eggs early in the egg-laying phase, but typically accept eggs. Females have been observed behaving aggressively towards female cowbird models (Mark and Stutchbury 1994). Typically, one or two BHCO eggs are laid in HOWA nests and one or more HOWA eggs are removed by the female Cowbird just after dawn. Cowbird chicks are fed by HOWA foster parents, and with their larger size, outcompete HOWA chicks in the nest, usually causing their death by starvation or ejection from the nest.

Despite the large percentages of HOWA nests parasitized by BHCO, removal of cowbirds and their eggs has been shown to have minimal impact on improving reproductive success (Stutchbury 1997). This may be due to the fact that the principal cause of nestling mortality in these study areas was nest predation (which is also increased by fragmentation and edge effects).

Management techniques: Due to the abundance and widespread distribution of HOWA on a continental scale, no management techniques are urgently required. However, locally imperiled populations may be aided by management. Selective logging may increase canopy gaps and shrub dominance required by breeding HOWA, and the subsequent increased health and connectivity of shrub layers may help to abate the effects of fragmentation and habitat loss (Gartshore 1988, Whittam et al. 2002). Preservation and protection of existing habitat in regions where wintering or breeding habitat is increasingly disturbed and/or declining will help HOWA and many other

species. Systematic removal of BHCO can possibly have a dramatic impact on increasing reproductive success, but only if nest predation can be reduced by predator control measures (Stutchbury 1997).

Japanese Barberry (*Berberis thunbergii*)

Taxonomy

Japanese Barberry is an angiosperm plant in the Family Berberidaceae and Order Ranunculales. Other plants in the Berberidaceae include the native American Barberry (*B. canadensis*), the introduced and naturalized Common Barberry (*B. vulgaris*), as well as the native groundcover plant Mayapple (*Podophyllum peltatum*) (Swearingen 2009). Many distinct varieties of *B. thunbergii* have been cultivated for use as ornamental landscaping plants, and it is widely available in nurseries and garden centers.

Morphology

Japanese Barberry is a woody deciduous shrub that averages 0.5-2.5m tall (Swearingen 2009). This shrub has dense foliage made of small ovate, spatula shaped leaves, which are 1-2cm in diameter. The branches have alternately arranged and closely spaced nodes, each containing a cluster of 2-6 leaves and typically one (but occasionally three) spines (Fig. 14). Spines, which are modified leaves, are about 1 cm long, and needle-like. Shrubs contain many woody stems with branches that form dense interlocking tangles. Japanese Barberry commonly grows in dense thickets made

of many individual shrubs. Foliage color is variable and changes seasonally. Plants growing in shaded forest understory (where the plant is naturally found) have vibrant light green colored leaves in spring and early summer that become dark green by the end of the growing season, and become yellow before falling in autumn (Fig. 12-13). When growing in full sun, leaves turn a dark burgundy-red or maroon color, which is popular in landscaping (MI DNR 2012 Feb) (Fig. 13). Cultivars have been developed that display leaf colors from bluish-green to deep purple in color. Flowers are a pale yellow color, approximately 8 mm in diameter, and form drooping umbel inflorescences of 2-5 flowers that resemble an upside-down umbrella (Fig. 14). Fruits are 7-10 mm long ovate berries, bright red to orange-red in color, and containing a single seed (Swearingen 2009) (Figure 14). *Berberis thunbergii* is distinguished from similar *B. canadensis* and *B. vulgaris* by having smooth margined leaves lacking serrated edges and umbel rather than raceme inflorescences.



Figure 12. Photograph of Japanese Barberry leaves by James H. Miller, USDA Forest Service (Miller).



Figure 13. Japanese Barberry exhibiting two different leaf colors. Photographs by B. Swayser and Jerzy Opiola respectively (Opiola 2005).



Figure 14. *B. thunbergii* fruits (left), and flowers in umbel inflorescences (right). Photographs taken by MPF and Sage Ross respectively (Ross 2009, User:MPF 2014).

Phenology

Japanese Barberry leaves emerge in early spring (late March in the study area), which is approximately one month prior to the leaf-out of most canopy tree species that grow above them (MI DNR 2012). The plant undergoes a second leaf-out in mid to late spring (mid-May) (Xu et al. 2007). Flowers bloom from mid-April to early May, and are lost fairly quickly. Flowers are pollinated by a variety of bee species (Lebuhn and Anderson 1994). Berries form as early as late-summer and begin to mature by fall, persisting on stems into winter. Mature berries are consumed by many animals, especially birds and deer, and seeds are dispersed by gravity and via bird and deer droppings, among other mechanisms. Birds will either eat the flesh of fruits and discard the seeds, or swallow the berries whole, digesting the flesh and excreting the seeds, both of which serve as dispersal mechanisms (Silander and Klepeis 1999). Seedlings can grow up to 1.2 m in their first growing season (MI DNR 2012). In addition to seed dispersal, the plant can also disperse itself laterally through the soil via rhizome growth or through clonal shoot growth of any foliage touching the ground (DeGasperis and Motzkin 2007, MI DNR 2012). Leaves are dropped in October, with woody stems and spines persisting year-round.

Natural History

Native Distribution: Japanese Barberry is native to Japan, specifically the southern and central regions of the country where it was first discovered in a

mountainous area in 1864 by Russian botanist Carl Maximowicz (TNC 1996, DeGasperis and Motzkin 2007). In its native range, the plant typically inhabits mountainous areas with either temperate or subtropical climates, but can also be found inhabiting disturbed areas with mesic conditions (Cassidy 2002).

Introductions: Japanese Barberry has been widely introduced throughout eastern Asia (notably China) and roughly the eastern two thirds of North America, including all of the northeastern U.S. and southeastern Canada (Harrington et al. 2004, Harrington 2005). This species is now found as far west as the states of Washington and Wyoming, and in every state to the east of Wyoming except the Dakotas, Oklahoma, Arkansas, and those bordering the Gulf of Mexico (University of Georgia 2017). In Canada, the provinces of Prince Edward Island, New Brunswick, Nova Scotia, Quebec, and Ontario all contain Japanese Barberry populations (University of Georgia 2017) (Fig. 14). It thrives in an impressive myriad of habitats throughout its introduced range including woodland edges, roadsides, stream banks, old fields, and forests of many compositional types from early successional through climax communities. It may be most abundant in forests that have regrown from abandoned agricultural fields and pasturelands (MI DNR 2012). Japanese Barberry tolerates a wide range of soil and moisture conditions and is tolerant of full-shade to full-sun in its introduced range (MI DNR 2012).

Japanese Barberry was first introduced into North America in 1875 when plants were imported to the Arnold Arboretum in Boston, Massachusetts from the St.

Petersburg Botanical Gardens in St. Petersburg, Russia (TNC 1996). By the beginning of the 20th century it had become a common ornamental shrub throughout New England and shortly after 1910 had become established in forests throughout the region.

Japanese Barberry was also planted at the New York Botanical Garden in 1896, and likely spread from this location as well (Swearingen et al. 2002). It has spread through North American forests ever since to occupy its current range (Fig. 15).

In addition to its major Asian and North American introductions, *B. thunbergii* has also been introduced to Australia, Austria, Denmark, Finland, Georgia, Germany, Netherlands, Italy, and Poland (Harrington 2005).

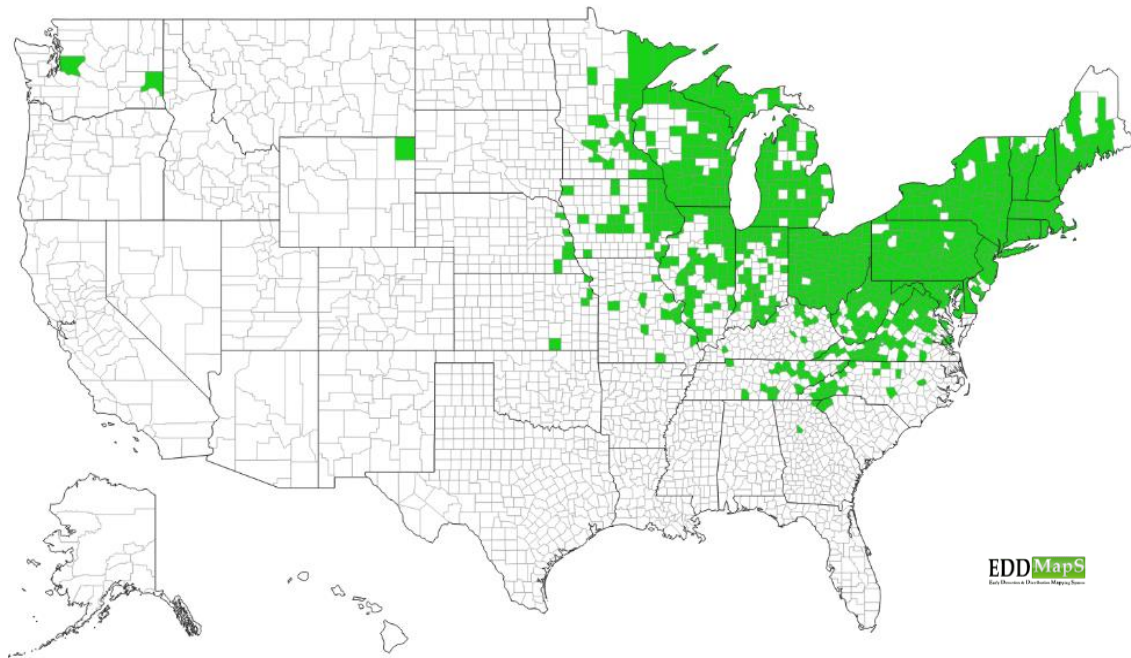


Figure 15. Map of Japanese Barberry's current range of distribution in North America (University of Georgia, 2017).

Invasion Ecology in North America: Invasive species are a major threat to global biodiversity, and it is estimated that 42% of the species on the United States Threatened and Endangered Species lists (U.S. Endangered Species Act) are imperiled primarily due to exotic invasive species (Pimentel et al. 2005). Many ecologists agree that success as an invader is made more likely when species possess a suite of common traits. Successful invasive species often have high reproductive rates, short generation times, excellent dispersal abilities, asexual reproduction, high natural genetic diversity, phenotypic plasticity, broad native ranges, generalist tendencies, and are often human commensals (Williams and Meffe 1998, Kolar and Lodge 2001).

Japanese Barberry is recognized as one of the most problematic exotic invasive land plants in northeastern North America, and it exemplifies many of the above traits (Silander and Klepeis 1999). Japanese Barberry has high growth and reproductive rates and short generation times, with individual plants growing up to 1.2 m tall and producing many fertile seeds within their first growing season (MI DNR 2012). This plant is also highly effective at seed dispersal, relying on wildlife to widely disperse its seeds, mainly through the droppings of birds and mammals. Many different bird species feed upon the fruits and disperse the seeds, including gamebirds such as Wild Turkey (*Meleagris gallopavo*) and Ruffed Grouse (*Bonasa umbellus*), and passerines such as Gray Catbirds (*Dumetella carolinensis*) and American Robins (*Turdus migratorius*) (NPS 2010). White-tailed Deer are also considered to be an important agent in seed

dispersal. Additionally, Japanese Barberry exhibits asexual reproduction in the form of clonal shoot growth. Japanese Barberry exhibits high phenotypic plasticity and genetic diversity, enabling it to adapt easily to a wide variety of habitats and growth conditions and act as a generalist (PA DCNRa). Finally, it is a good human commensal, thriving and spreading in urban and suburban areas where it is planted. Its widespread use and success as an ornamental and landscaping plant contribute heavily to its successful invasion. Even if all Japanese Barberry plants were hypothetically eradicated from natural settings, it would soon return due to seed dispersal from the huge stock grown in shopping centers, nurseries, housing developments, and similar places across North America (Brand et al. 2012).

An important additional factor that has led to Japanese Barberry's success as an invader in North America is its ability to outcompete other plants due to several traits. As mentioned above, Japanese Barberry is given a distinct competitive advantage over native shrub and sapling species due to its avoidance by the White-tailed Deer over-browsing (deer eat barberry berries but not leaves) that plagues native understory plants (Aronson and Handel 2011). Japanese Barberry also raises the soil pH of the area around its roots, creating conditions too basic for many other plants to grow although Ash species (*Fraxinus* spp.) prefer this, thus altering microbial communities in the soil to better suit its own growth (Kourtev et al. 2002, Harrington et al. 2004, Swearingen 2009). Japanese Barberry is better able to uptake nitrogen compounds from the soil than many native plant species which gives it a competitive advantage, especially in

nitrogen-poor soils. It also modifies nitrogen cycling to suit its own growth (Ehrenfeld et al. 2001). This plant excludes competitors by growing in such dense stands that it blocks sunlight from reaching any seedlings close to the ground. In addition to blocking growth of other plants above ground, Ehrenfeld (1999) found that Japanese Barberry roots form a large mass in shallow soil layers that likely inhibits the growth of native plant roots such as those of blueberry (*Vaccinium* spp.). Research has also shown that Japanese Barberry is much more resistant to herbivory than many native species, tolerating defoliation with little negative impact on the plant's physiology, which gives it an additional competitive advantage (Vanderklein et al. 2015).

Additionally, it is thought that land use history in the eastern U.S. has helped aid Japanese Barberry's spread. Historical land disturbances such as fire, livestock grazing, logging, and agriculture have given Japanese barberry open niches to invade and outcompete native species (DeGasperis and Motzkin 2007).

Due to its ability as an invader, Japanese Barberry can drastically change the composition of forests formerly dominated by native plants. For example, Kourtev et al. (2002) found that Japanese Barberry was replacing native blueberry and huckleberry shrub species (*Vaccinium* spp. and *Gaylussacia* spp., respectively) in New Jersey. Kourtev et al. (2002) also observed that areas with dense Japanese Barberry growth had fewer oak trees but an increased abundance of white ash and tulip poplar.

Japanese Barberry suppresses the regeneration of shrubs and trees by preventing the growth of shrub seedlings and saplings (Aronson and Handel 2011). This

results in forests that are dominated by large mature trees which make up the canopy layer, an understory layer dominated by Japanese Barberry, and a mostly absent mid-story or lower level canopy (Fig. 20). This reduction of forest complexity and native plant biodiversity has negative consequences on organisms that rely on these plants and forest layers for food, shelter, and reproduction (Ehrenfeld 1997, Tallamy 2007). When the mature trees eventually die, once-healthy forests can become barberry thickets. This invasion is especially detrimental to native insects that rely on native plants for food, and consequentially to the birds and other animals that consume these insects. This invasion causes a decrease in lepidopteran larval densities, which are the primary food source for breeding parulid warblers (Burghardt et al. 2010).

Use of Japanese Barberry by Native Fauna: Despite its undeniably negative impact on the native ecosystems that it invades, Japanese Barberry is used by many animal species. The foliage of Japanese Barberry is comprised of small dense leaves that maintain a relatively high level of humidity and therefore act as an excellent host for Black-legged/Deer Ticks (*Ixodes scapularis*), and their nymphal host White-footed Mice (*Peromyscus leucopus*). Specifically, studies have shown that higher densities of questing nymphal and adult black-legged ticks take shelter in Japanese Barberry than in native plants (Elias et al. 2006). Since these ticks are responsible for vectoring *Borrelia burgdorferi*, the causative agent for Lyme disease in humans, Japanese Barberry has become a vilified exotic invasive species by many living in the northeastern U.S. (MI DNR 2012).

Several shrub-nesting bird species have been observed nesting in Japanese Barberry. Veery (*Catharus fuscescens*) nested in Japanese Barberry with reduced predation rates when compared to nests in native shrubs (Schmidt et al. 2005). Larger mammalian predators such as Raccoons were not deterred by the spiny plant, but it deterred smaller mammalian predators such as rodents. An additional study investigated this behavior as a possible ecological trap, but showed that Veery nesting in exotic plants including Amur Honeysuckle (*Lonicera maackii*), Multiflora Rose, and Japanese Barberry, did not experience decreased reproductive success and likely preferred nesting in these plants due to increased foliage density as compared to native plants (Meyer et al. 2015).

Gray Catbirds (*Dumetella carolinensis*) were also found to nest in Japanese Barberry, but not significantly more so than in other shrub species (Nickell 1965). In a separate study, Gray Catbirds were found to prefer a suite of exotic invasive plants (including *B. thunbergii* and *R. multiflora*) to other nesting substrates and bred more successfully in these plants (Schlossberg and King 2010). This study also found Chestnut-sided Warblers (*Setophaga pensylvanica*) commonly breeding in these invasive plant species, but this species showed no preference for, or increased reproductive success using, invasive nesting substrate. Schlossberg and King (2010) also found no differences in avian success or preference between different exotic invasive plant species or between invasive plant species with or without thorns/spines.

Hooded Warblers have been observed nesting in Japanese Barberry on multiple occasions, but nesting in this plant exclusively was not quantified and was not the focus of these studies (Schlossberg and King 2010, Garrett 2015). Garrett (2015) quantified the use of exotic invasive plants by HOWA, and found a significant preference for exotic plants, especially *Rosa multiflora*, introduced honeysuckles (*Lonicera* spp.), and European Privet (*Ligustrum vulgare*), but including Japanese Barberry to a lesser extent. He found no significant difference in nesting success between exotic and native substrates, but found higher fledging success from nests in Multiflora Rose than from those in European Privet (Garrett 2015). Garrett concluded that stands of exotic invasive shrubs which are avoided by or resilient to over-browsing by White-tailed Deer may be valuable nesting areas for shrub-nesting birds in habitats depleted of native-understory.

Previous East Stroudsburg University student Jennifer Kutch (2013) used avian point counts to show that HOWA had a significant preference for choosing to sing and defend breeding territories in stands of Japanese Barberry over native understory plant species. The current study aimed to follow up on Kutch's work and advance this previous research by investigating questions it left unanswered.

Both HOWA and Japanese Barberry have experienced similar range expansions in eastern North America in that past century, although to different extents. Figure 16 shows range maps for both species from the Global Biodiversity Information Facility from 1960 to present. While these maps do not represent the full occurrences of these

two species, especially due to the relative unavailability of data prior to the digital age, note the increase in density of both species in the same areas near the Atlantic coast (GBIF 2017). Maps are shown in 20 year intervals from 1960 to 2017, with 2012 included for better comparison with 2017 (both years when the internet was widely used to share data).

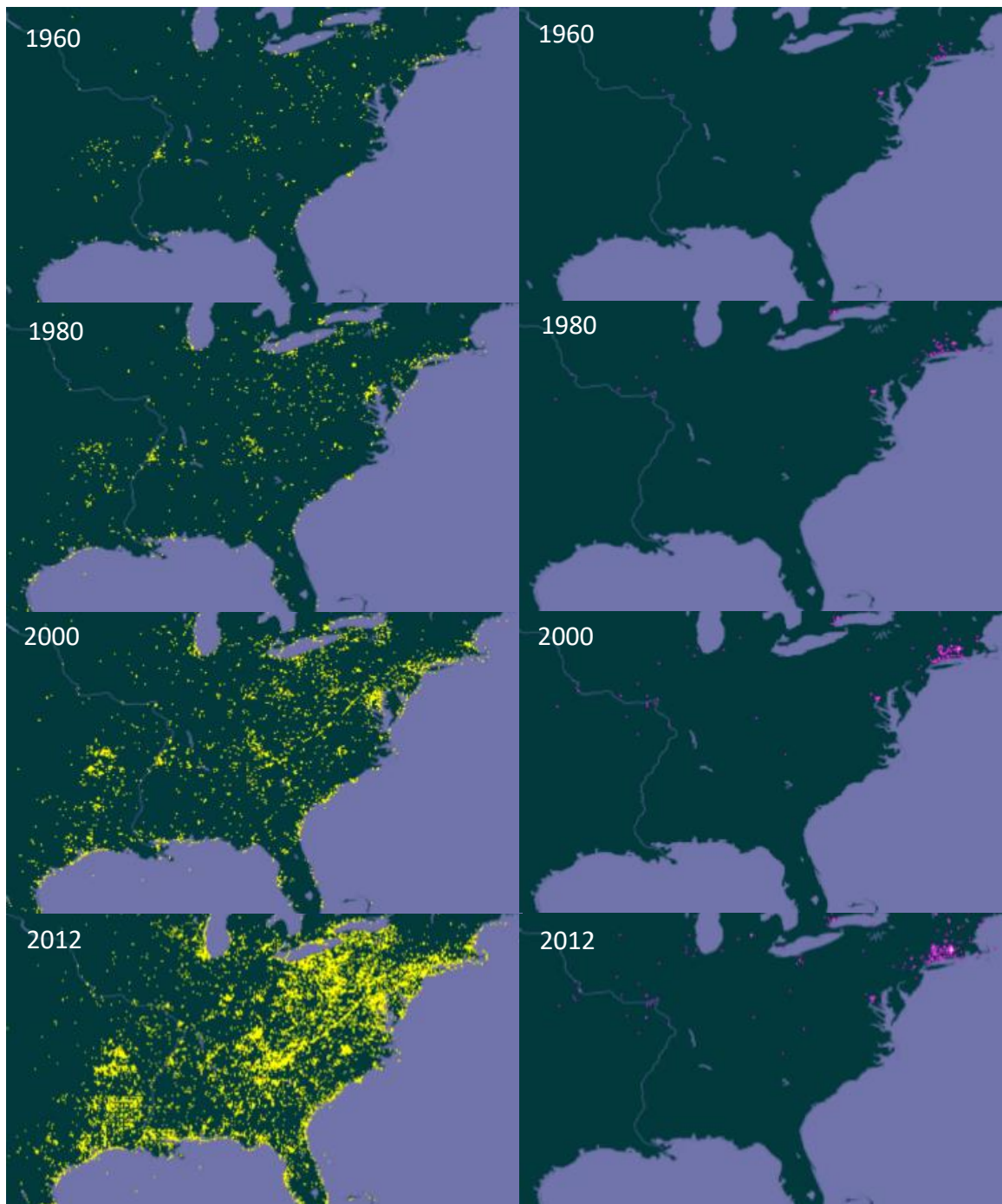


Figure 16. Range maps of HOWA (left, yellow points) and Japanese Barberry (right, purple points) from 1960 to present. Note matching high density population areas near the Atlantic coast (GBIF 2017). Continued on next page.

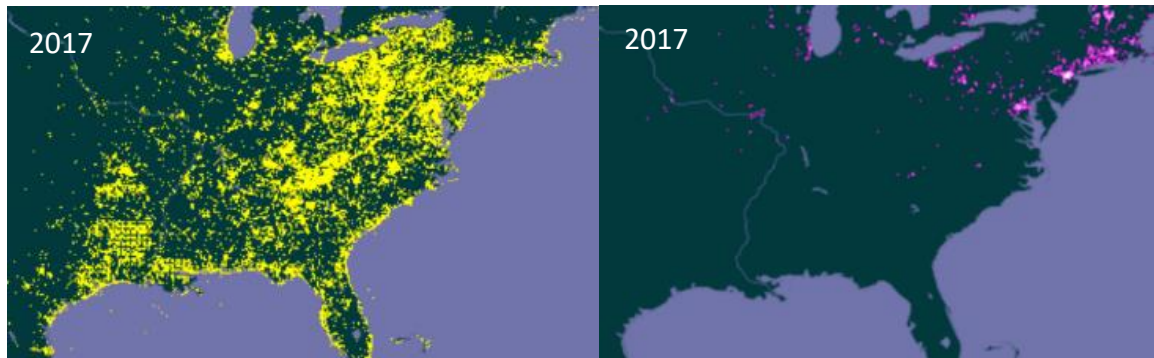


Figure 16 continued. Range maps of HOWA (left, yellow points) and Japanese Barberry (right, purple points) from 1960 to present. Note matching high density population areas near the Atlantic coast (GBIF 2017).

Study Area

This study took place in the Delaware Water Gap National Recreation Area (hereafter DEWA), which is a 27,009 ha (66,740 acres) parcel of federally-owned land, managed and operated by the National Park Service, a division of the United States Department of the Interior. DEWA occupies land in both northeastern Pennsylvania and northwestern New Jersey, and is roughly bisected by a 66 km stretch of the middle portion of the Delaware River (Sheehan and Master 2010) (Fig. 17). This recreation area occupies portions of Northampton, Monroe, and Pike counties in Pennsylvania and Warren and Sussex Counties in New Jersey. DEWA contains a reach of the Delaware River which represents the longest undammed stretch of any major river in the eastern United States. It is designated as a Wild and Scenic River and is considered to have the highest water quality of any major river east of the Mississippi (NPS 2016a).

DEWA is named after a geographical feature that makes up the southern portion of the park, the Delaware Water Gap. This gap is where the Delaware River cuts through the Appalachian Mountain Range within the Blue Mountain Section of the

Valley and Ridge Physiographic Province of Pennsylvania (PA DCNRb). DEWA contains a variety of natural habitats, including deciduous forests of varying ages, hemlock ravines, floodplains, high gradient rushing mountain streams, wetlands, marshes, and swamps. The area has a rich agricultural history which is reflected by continuing farming operations within the park (NPS 2016a).

This study was conducted in the southern half of DEWA and New Jersey's Worthington State Forest (hereafter WSF). WSF is a 2,695 ha state park embedded within the southernmost portion of the New Jersey side of DEWA and managed by New Jersey's Parks and Forestry Division of the state's Department of Environmental Protection. Of the 10 study blocks, four were located in Monroe County, PA, five were located in Warren County, NJ, and one was located in Sussex County, NJ. This study site was chosen due to its close proximity to East Stroudsburg University, its known populations of HOWA and Japanese Barberry, the National Park Service's willingness to allow scientific research on this land, and recognition by park personell that Japanese Barberry represents a habitat managmenet issue.

History:

In the early 1950s intital consideration was given to the construction of a dam across the Delaware River near Tock's Island (Albert 2010). Tock's Island is just north of the Delaware Water Gap, in the southern portion of the present day National Recreation Area. In the mid-1950s, two hurricanes brought significant flooding to the middle Delaware River and its tributaries. Hurricane Diane in 1955 caused flooding that

led to several dozen fatalities (Albert 2010). The need for flood control in this area became nationally recognized, and by 1965 the U.S. Congress approved a plan to build the Tock's Island Dam. This dam would have created a reservoir approximately 64 km long and 1.6 km wide, with a large Tock's Island National Recreation Area surrounding the reservoir. The reservoir would have contained a pump system to provide water to New York City, Philadelphia, and surrounding developed areas, and a hydroelectric power plant was also proposed for the dam (Albert 2010).

The United States Government began acquiring the land needed for this project through eminent domain and condemnation of private properties. This process and the proposed dam incited massive controversy from residents, environmental activists, and others, and the project was heavily protested (Feiveson et al. 1976). Due to local opposition and governmental financial difficulties (resulting mostly from the Vietnam War), the dam project was abandoned in 1975 (Albert 2010). Despite the demise of the Tock's Island Dam project, most of the land had already been obtained by the federal government and the existing park became the Delaware Water Gap National Recreation Area in. The Tock's Island Dam project was revisited in 1992 and again in 2002 when it was officially and finally de-authorized. Today DEWA is a popular scenic recreation area among vacationers and local residents, hosting about 5,000,000 visitors per year, making it one of the most visited units of National Park system (NPS 2016a).

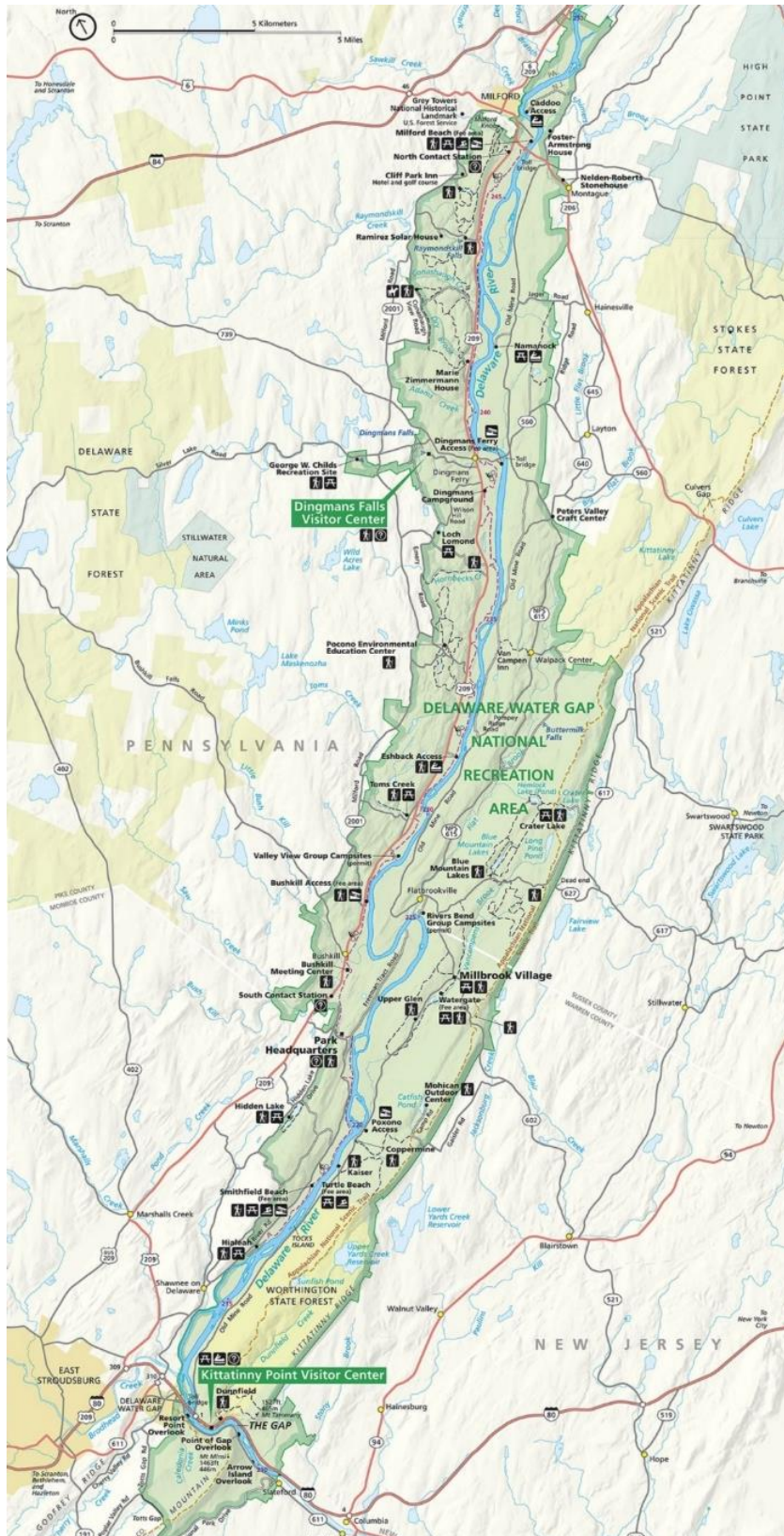


Figure 17. Map of the Delaware Water Gap National Recreation Area (NPS 2016).

Objectives and Project Rationale

The general objective of and rationale for this study was to determine whether Japanese Barberry-dominated understory habitat is superior to native plant dominated understory with regard to HOWA productivity and nesting success by confirming, quantifying, and explaining the relationship between HOWA and the presence of Japanese Barberry. This study and that of Kutch (2013) are the first research efforts designed to specifically evaluate the use of Japanese Barberry as a nesting substrate by HOWA. Preferential use of barberry nesting substrate/habitat has been observed, but not quantified with for HOWA (Schlossberg and King 2010, Garrett 2015), while the preferential use of exotic invasive nesting habitat (not limited to barberry) by HOWA has only been quantified once (Garrett 2015). This was the first attempt to quantify measures of habitat affinity (age and site fidelity) and reproductive success of HOWA in Japanese Barberry-dominated vs. native-dominated habitats through banding. In-depth vegetation analysis of HOWA territories (both in Japanese Barberry and native-dominated understory) was conducted and compared to nearby random available habitat. Chiver et al. (2011) recognized that little is known about the selection of breeding habitat in this species and that investigating this topic is a priority for future research.

Ultimately, we hope to learn more about the relationship between Hooded Warblers and Japanese Barberry, and objectively contribute to the current knowledge base regarding this native bird and exotic invasive plant. Although exotic invasive plants

are a major conservation concern (Tallamy 2007, Burghardt, et al. 2010), little doubt exists that some species will never be fully eradicated due to the sheer scale and pervasiveness of their invasions, thus, documentation of any potential benefit provided by these plants represents a valuable contribution to wildlife biology and habitat management.

Kutch's (2013) prior work led to several additional avenues of research that helped to coalesce the specific objectives of this study: (1) determining whether HOWA detection frequency corroborates breeding frequency; (2) whether HOWA nests built in Japanese Barberry have a higher or lower reproductive success rate than nests built in native understory; (3) if individuals with territories in Japanese Barberry are older, more experienced birds (beyond their first breeding season) and therefore choose more favorable nesting habitat; (4) determination of whether breeding site fidelity correlates with previous reproductive success, and if fidelity will be higher in Japanese Barberry-dominated territories; (5) investigating whether vegetation structure and composition in HOWA territories differ from nearby random available habitat and; (6) determining if vegetation structure and composition in Japanese Barberry-dominated territories is more preferable to HOWA than native understory-dominated territories.

From the above objectives, the following null hypotheses were generated: (1) there will be no differences in HOWA nesting or territory frequencies between native-dominated and Japanese Barberry-dominated understory habitat types; (2) there will be no differences in HOWA reproductive success between native-dominated and Japanese

Barberry-dominated understory habitats; (3) individuals with territories in Japanese Barberry-dominated understory will not be older on average than birds occupying territories in native-dominated understory; (4) during the second field season, birds banded and recaptured will choose nesting habitats that show no correlation with their previous reproductive success, and fidelity will not differ by habitat plot type; (5) vegetation structure and composition will not differ significantly between nesting territories and random available habitat and; (6) vegetation structure and composition in Japanese Barberry-dominated territories will not better align with known HOWA breeding habitat preferences than native-dominated understory territories.

CHAPTER II

Methods

Study Site

Survey Blocks within DEWA

This study was performed in the southern half of the Delaware Water Gap National Recreation Area. Kutch (2013) overlaid a map of DEWA with a 2 x 2 km grid (creating 4 km² blocks) using the ArcMap® application of Esri ArcGIS 10.5® (Redlands, CA; 2016). Thirteen original survey blocks were chosen in a stratified random manner from the southern portion of DEWA on this map, with 10 of these being used for the final study. This same method was used to choose study sites for this project (Fig. 18). Each block was given a number from 1-10, with the northernmost block being 1 and the southernmost block being 10 (Fig. 19). Of the ten survey blocks used in Kutch's study, eight were retained for this study, while two blocks were replaced with blocks outside of the original 13. Kutch's two northernmost blocks on the New Jersey side of DEWA were replaced with two new

blocks off Freeman Tract Road on the Pennsylvania side due to travel distance concerns as well as a lack of adequate native understory-dominated habitat. Initial site surveys were conducted in April 2016 to gain familiarity with the study blocks, confirm Kutch's locations, and take GPS coordinates of each block. Appendix III gives GPS coordinates for study plots of each survey block.

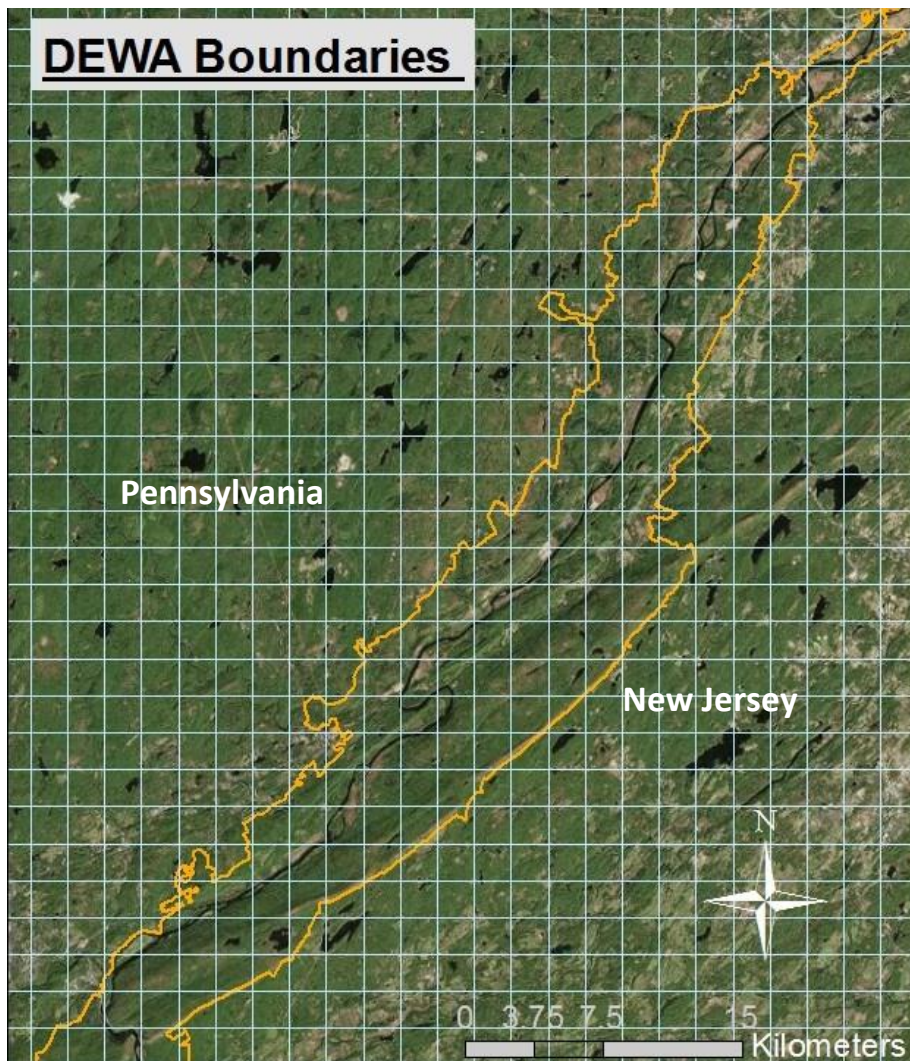


Figure 18. Map showing the perimeter boundary of the Delaware Water Gap National Recreation Area (orange line) as of 2015 with a 2x2 km grid overlay. Boundary shapefile courtesy of Kathy Commisso, NPS. Map by B. Swayser.

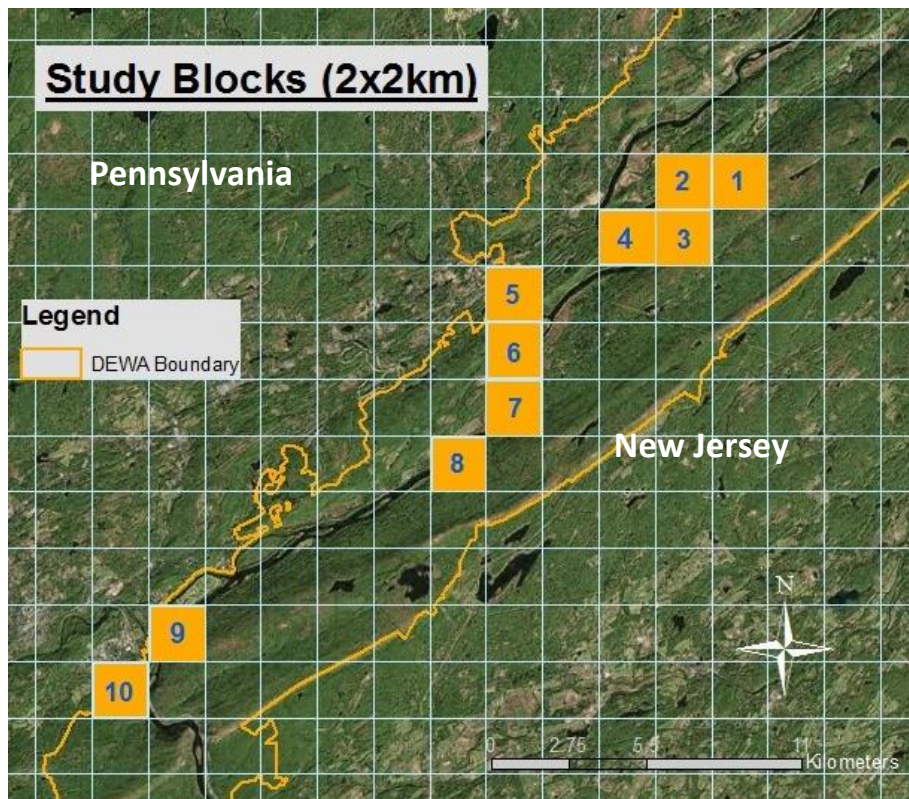


Figure 19. Map showing the southern half of DEWA with ten 2x2 km study blocks shown in orange and numbered. Map by B. Swayser.

Selection of Habitat Plots within Survey Blocks

Three study plots were established in each survey block: one with understory flora dominated by Japanese Barberry, one dominated by native understory plant species, and a third with a roughly equal mix of Japanese Barberry and native understory plants (termed transitional). Figures 20-22 show representative photographs of each plot type. For the purpose of this study, “native” understory is considered to be understory consisting of mostly native shrub and sapling species based upon visual inspection, while “transitional” is considered to be understory consisting of roughly equivalent amounts of native species and barberry, again as noted by a visual inspection. These areas likely will transition to being dominated by Japanese Barberry in

the near future. Japanese Barberry plots were areas that appeared to be mostly dominated by Japanese Barberry. This initial classification of plot types was supported by a detailed vegetation analysis done after plot boundaries were determined (Tables 9-11).

Each plot was a minimum of 250 meters from the next closest plot, a suggested distance to eliminate overlap when using song cues to, in part, survey passerine territories (Reynolds et al. 1980, Ralph et al. 1995, Kutch 2013), and each was roughly 6 ha (15 acres) in area. Plots were selected to be close to roads and/or trails so that multiple plots could be visited in the same day in order to maximize surveying efficiency. Figure 23 shows a map of plot locations, and GPS coordinates of each plot are listed in Appendix III. In each plot, the desired dominant vegetation type (Japanese Barberry-dominated, native understory-dominated, or transitional) extended a minimum of approximately of 100 meters in all directions from the center of the plot.

The selection of these three plot types (Japanese Barberry-dominated, transitional, and native) in the experimental design helped to facilitate data analysis, and to aid in study site organization. It also helped ensure that we analyzed the full range of variation in levels of barberry invasion at a given site. The main focus of the study sites however is the presence or absence of Japanese Barberry dominance in the understory, and several of the statistical analyses presented here take into account the presence or absence of Japanese Barberry dominance in study sites, without regard to their plot type.



Figure 20. Example of a Japanese Barberry-dominated study plot. Photograph taken in block three, 5 June 2017 by B. Swayser.



Figure 21. Example of a native understory-dominated study plot. Photograph taken in block 10, 5 June 2017 by B. Swayser.



Figure 22. Example of a transitional study plot. Photograph taken in block five, 5 June 2017 by B. Swayser.

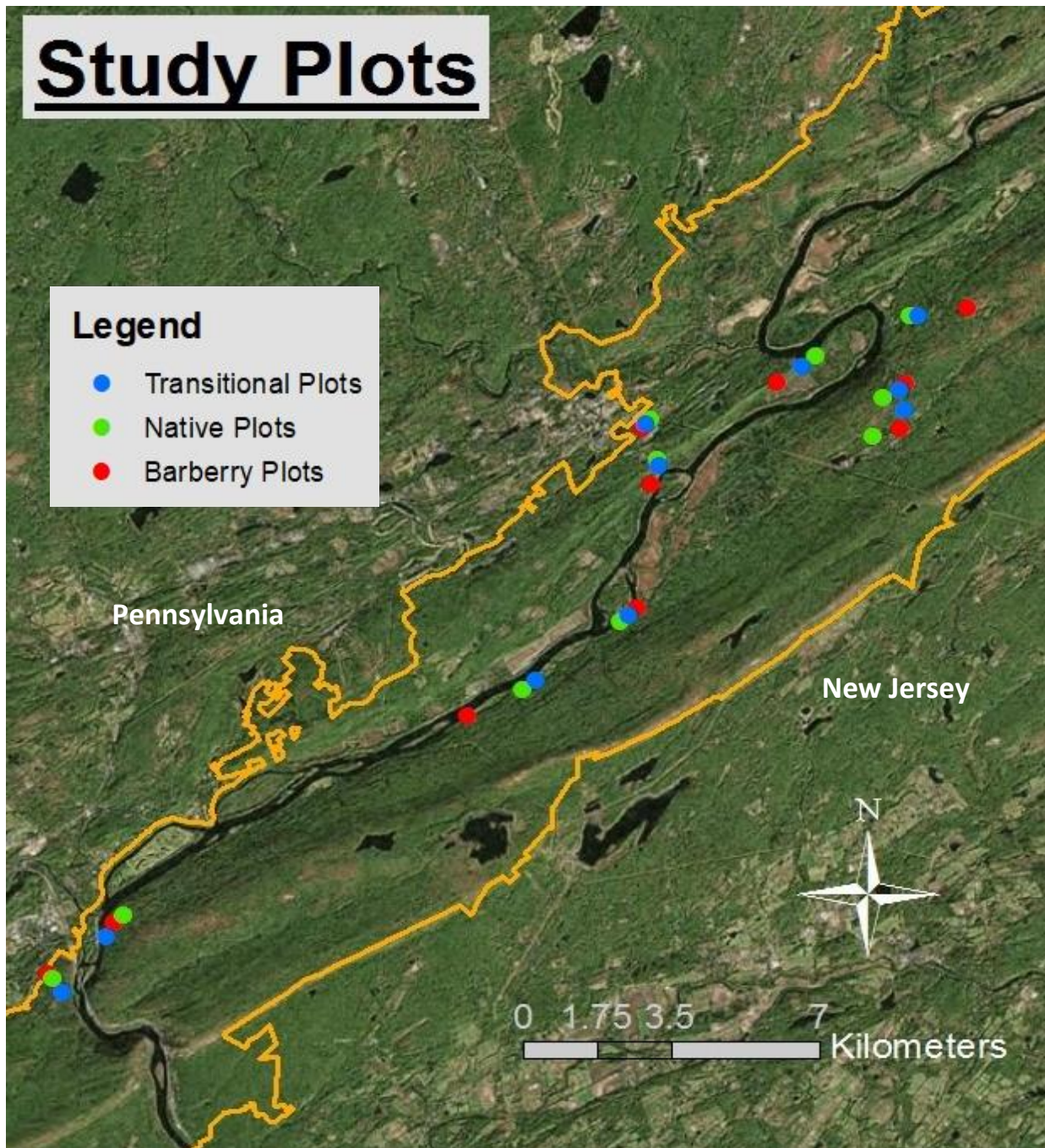


Figure 23. Map of the 30 plots used in this study; 10 transitional, 10 native-dominated, and 10 Japanese Barberry-dominated. Orange line represents DEWA boundaries. Map by B. Swayser.

Locating Territories and Nests

Each plot was surveyed for HOWA. Birds were located primarily by male song, HOWA's distinctive chip call, and visually. Once singing males were located, each individual was observed and audio playback was used as needed to determine the territorial boundaries of the pair. Each defended territory was given a randomly generated number between 0 and 100. Male territories were marked as "confirmed paired" if a female was seen spending substantial time in the territory, "unpaired" if it was clear that no females were present, or "uncertain" if it was not clear whether the male had paired with a female. An initial GPS waypoint was taken with a handheld Garmin® 60cxs GPS unit to help relocate the territory. After confirming that a territory was established (male observed defending the territory for several weeks), six GPS coordinates were taken of males singing from various song perches in their territories in order to establish territory boundaries. These territory boundaries were later plotted in ArcMap® to determine approximate territory area.

Once each territory had been delineated, suitable shrubs and other low vegetation were searched for nests. Nest searching was aided by listening for chip notes of females. An irregular chip note pattern signaled that a female was building a nest and gathering construction materials, and a regularly spaced chip note signaled that the female was taking a break from incubating in order to forage (Stutchbury pers. comm. 2017). When a chip note had been heard in a particular area for any duration, a method of systematic walking with the aid of a sweeping stick was employed to attempt

to locate the nest (Winter et al. 2003). A two-foot long dowel rod with a colored tip was laid in the direction of the bird while a second rod was used to gently move branches in the area and look for a nest. Optimal habitat areas (dense shrubs 0.5-2 m high near canopy openings) were emphasized during these searches (Chiver et. al 2001). Nest locations were recorded by taking GPS coordinates. Each nest shrub was identified to species and plot type (Japanese Barberry, transitional, or native) and the block number was recorded. A small amount of flagging tape was applied to a nearby branch in one situation where re-finding the nest proved difficult. Attempts were made to find an active nest in each located territory of each and every study plot and block. Old and/or abandoned nests were also recorded.

Measuring Reproductive Success

The predetermined parameters for measuring reproductive success included pairing success, pair density, nesting density, and fledgling density. Extensive nest monitoring was performed when nests were located. Each nest was assigned a random number that determined a visitation schedule which would allow each nest to be monitored every three days from first egg laid through fledging. Fledgling success was not measured due to the quantity of territories monitored and difficulties locating fledglings, despite its proven effectiveness in supplementing reproductive success metrics (Stutchbury et al. 1994). The data collected, including the number of eggs laid, egg fate, number of nestlings, and the number of nestlings that fledged was to be used

to determine overall nesting success. Any obvious signs of nest predation, nest destruction, or nest parasitism were recorded. Statistical analysis of these measures of reproductive success in all three habitat plot types (Japanese Barberry-dominated, transitional, and native understory-dominated) was planned. Great care was taken to not disturb nests, females, and/or chicks when searching for and observing nests.

Measuring Age-class Usage and Fidelity

At each HOWA territory, attempts were made to band both members of the breeding pair. All banding work was permitted by the Federal Bird Banding Lab (under the auspices of the United States Geological Survey), Pennsylvania Game Commission, New Jersey Division of Fish and Wildlife, the National Park Service, and the East Stroudsburg University Institutional Animal Care and Use Committee (permit numbers listed in Appendices I and II). Males were expected to be caught disproportionately more than females since they are largely responsible for territory defense (Chiver et al. 2011). A wooden male HOWA decoy was placed by the mist net in some situations to attract males. After each targeted bird was captured, the bird was banded, aged, and sexed (Pyle 2001). A standard size 0 aluminum USGS issued butt-end leg-band was applied to the right leg of the bird along with a single plastic color leg-band denoting which field season it was banded in. Birds banded in 2016 received red/white (two-colored band) or black color bands on their right legs, while 2017 birds received red bands on their right legs. Individually unique color combinations of two plastic bands

were applied to the left leg of each bird (Fig. 24). The four band combination totaled less than 3.0% of average HOWA body mass (11 g), as per USGS regulations.

Color bands were applied to birds to facilitate gathering of site fidelity data in future years. Unique left leg color combinations and year-specific right leg color bands



Figure 24. Male Hooded Warbler with USGS aluminum butt-end band 2820-02702 and plastic red/white 2016 band on right leg, and two plastic light blue bands on left leg. Banded 9 May 2016. Photograph by Terry Master.

allowed researchers to identify individuals from a distance with binoculars in order to determine individuals owning territories and site fidelity, without mist-netting the birds again.

Measurements taken on each bird included natural wing chord, rectrix length, body mass, and an estimate of fat storage in the furcular cavity on a scale of 0-6. Sex

was determined by behavior (males sing and aggressively defend territories), wing chord measurements, plumage traits (Fig. 26), and presence/absence of a cloacal protuberance or brood patch.

Age was determined using a combination of characteristics, as outlined by Pyle (2001). Tapered and worn rectrices, and presence of a molt limit (faded, abraded, dull, and/or discolored feathers) in the alulae and/or primary coverts indicated second year (SY) individuals, or those birds hatched in the previous calendar year and breeding for the first time (Fig. 25a). Fresh, unworn, and blunt/truncate tipped rectrices, and uniformly fresh wing coverts with even sheen, wear, and color, indicated after second year (ASY) birds, or those in their second or later breeding season (Fig. 25b).

Figure 25. Feather evidence for aging HOWA.

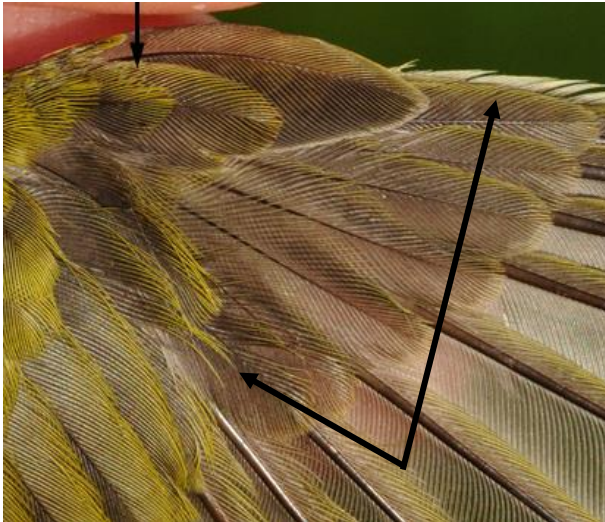


Figure 25a. Molt limit between 1st and 2nd alulae and in primary coverts (dull and abraded PC contrasting with fresh bright SC) (top). Heavily worn juvenile rectrices, tapered and abraded (bottom). Photographs by BandersResource.com.

Figure 25b. Alulae and all coverts uniformly fresh in wear and color (top). Fresh adult rectrices, truncate and full looking (bottom). Photographs by BandersResource.com.

Additionally, the pattern of black feathers in the “hoods” (face and head) of the birds were used, albeit to a lesser degree due to this trait’s variability, as criteria for aging (Pyle 2001). Young females average little to no black feathers in their hood region, while adult females gain a black border to their hood with the hood gradually filling in with black feathers as the bird ages. Older females can have heavily blackened hoods similar to males, although females always show at least a few scattered yellow hood feathers. Young males typically show completely black hoods, but with moderate to heavy yellow edging of black hood feathers, in addition to yellow chins and scattered black on the forehead. Older males show jet black hoods extending further down the forehead and often black chins with no yellow present. A pictorial summary of these sexually dimorphic plumage traits can be seen below (Fig. 26).

Figure 26. HOWA plumage traits by age and sex. Photographs a-c from Patuxent Wildlife Research Center, USGS. Pwrc.usgs.gov.



26a. SY female- No or very little black on face/head, molt limit, small wing chord, and juvenile tail. Photograph by Sandy Teliak.



26b. SY male- Full black "hood", feathers have yellow edging, molt limit, large wing chord, and juvenile tail. Photograph by Sandy Teliak.



26c. ASY female- Black on margins of "hood region", no yellow edging, no molt limit, small wing chord, and adult tail. Photograph by Mike Quinlan.



26d. ASY male- Full jet black "hood", no yellow edging, no molt limit, large wing chord, and adult tail. Photograph by B. Swayser.

Vegetation Analysis

Vegetation analyses were performed in each of the 30 habitat plots (Japanese Barberry-dominated, native understory-dominated, and transitional) within the ten study blocks from early July 2016 to early October 2016 and from mid-June 2017 through August 2017.

A modified version of the BBird protocol for vegetation analysis (Martin et al. 1997) was used as in Kutch's (2013) study, to characterize vegetation composition and structure. One vegetation survey was done in a randomly chosen available habitat area in each of the 30 plots and in the core of each occupied territory in order to compare occupied and unoccupied areas to determine if differences in vegetation structure and composition exist. Seventy-four vegetation surveys were done in total, including the 30 in random available areas and 44 in occupied territories, termed use areas (of the 49 territories, five territory locations were virtually identical between field seasons). Randomly generated numbers, one for compass direction and one for distance intervals (0 - 10 m, 11 - 20 m, 21 - 30 m, 31 - 40 m, and 41 - 50 m) from the approximate center of each territory, were used to locate the randomly chosen vegetation survey sites within each plot type. Distance intervals and compass directions that placed an available habitat survey site on a road, trail, or in a river or stream were avoided, and the next randomly generated combination in the sequence was used. Vegetation surveys of HOWA territories were centered on either the nest in a given territory, or in dense shrubbery near the center-most territory GPS coordinate (if the nest could not be

located). In some cases, HOWA territory vegetation survey sites did include segments of roads, trails, rivers etc. Protocol design and parameters are shown in figure 27.

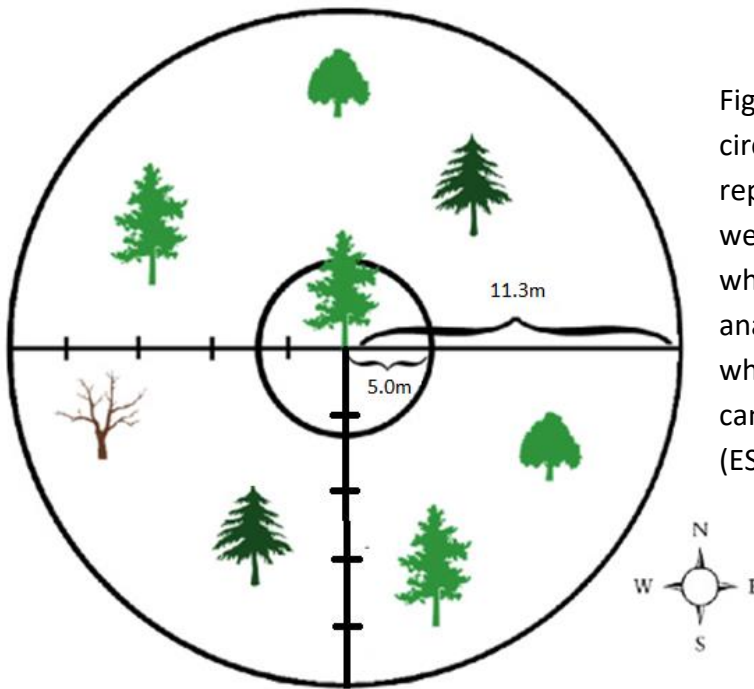


Figure 27. Example of a vegetation circle where the outer circle represents the area where trees were analyzed, the inner circle where shrubs and sapling were analyzed, and the hash marks where foliage distribution and canopy height were measured. (ESU 2013).

Trees

All living trees (defined as containing at least some photosynthesizing branches) greater than 8 cm in diameter at breast height (DBH) were identified and counted within an 11.3 m radius (0.04 ha) circle around the survey point denoted by two ropes with meter markings arrayed on the forest floor to represent all cardinal directions (Martin et al. 1997). This created four quadrants in the survey circle. All tree trunks and stems branching below 1.4 m were measured. DBH was measured using a Diameter at Breast

Height tape (Forestry Suppliers Inc., Jackson, MS). Trees were measured quadrant by quadrant to avoid confusion and confirm that all trees in the circle were measured.

Ecological Importance Values (IV) were calculated for all trees. IVs were calculated by adding Relative Density (number of individuals of a species divided by number of all individuals), Relative Dominance (total basal area of a species as calculated using DBH, divided by total basal area of all species), and Relative Frequency (number of surveys containing a species divided by total number of surveys).

Saplings

All live tree saplings within a 5 m radius (0.008 ha circle) of the center point which measured less than 8 cm in DBH were identified and counted. As shown in Fig. 27 above, the 5 m radius circle was centered within the original 11.3 m radius circular plot. The quadrant by quadrant style of measurement was also employed in this smaller circle. IVs were calculated as with trees.

Shrubs

Shrubs were sampled similarly to saplings, but were defined as vegetation with multiple woody stems less than 8 cm in DBH, where a main, central stem was not present. Within the same 5 meter radius circle used to measure saplings, all shrubs were identified. Estimates of the average height and the collective percent coverage of the circle by each shrub species were noted. For shrub species with distinct stems, all

stems in the shrub analysis circle were counted and the number of stems was listed by species. For shrub species with very numerous and highly intertwined stems and branches, stems could not be counted.

IVs were also calculated for shrubs. Since DBH cannot be practically measured for all shrubs, relative dominance was replaced with relative shrub coverage (total percent coverage of a species divided by total percent coverage for all species) (Baxter 2017). Since individual shrubs were not counted, relative frequency data was identical to relative density data and was thus removed from these calculations to avoid skewing IVs.

Understory Density

HOWA prefer nesting habitat within dense shrubby understory, presumably for nest concealment and protection from predators (Howlett and Stutchbury 1996, Chiver et al. 2011). Therefore, understory density was measured to discern differences in understory foliage density and thus differences in the degree of protection provided from predators between plot types and territory vs. random available sites. Using a protocol similar to Howlett and Stutchbury (1996) and De Groot and Smith (2001), a 1 x 1 m plywood board was divided into twenty-five 20 x 20 cm blocks (five blocks across and five blocks down) using permanent marker. At each vegetation survey site, the board was placed vertically at the center of the vegetation analysis circle, and faced in a cardinal direction (due N, S, E, or W). While standing 15 m from the board, a gridded

data sheet was used to estimate how much vegetation covered each block of the grid, and the height of the vegetation surrounding the board. The predominant shrub species at the board was also noted. A score of 0 was given for any block unobscured by vegetation, a score of 0.25 for any block that was less than 50% obscured, 0.5 for any block that was greater than 50% obscured, and a score of 0.75 for any block that was completely obscured. The process was then repeated in the opposite cardinal direction. These weighted values were then summed and the two cardinal directions were averaged to give a score of understory density for each survey area. This score was divided by 18.75 and multiplied by 100 to give a final understory density percentage.

Canopy Cover

A spherical densiometer (Forest Densiometers, Bartlesville, OK) was used to measure the canopy coverage at the center of each vegetation survey circle and at the 5 meter mark from the circle center in each cardinal direction. The number of equidistant dots within the squares on the face of the densiometer that were unobscured by foliage was counted and multiplied by 1.04, providing a measure of percent unobscured canopy. This was then subtracted from 100 to calculate the percent canopy coverage at each of the five measurement locations. The mean of these five measurements was calculated to determine the average percent canopy coverage of each survey plot. A canopy coverage measurement of around 70 percent or less in the field indicated a canopy opening (typically either a treefall gap or a disturbed edge), so if a vegetation

survey plot contained a canopy coverage measurement of $\leq 70\%$ it was recorded as containing a canopy gap.

Foliage Distribution

The two marked ropes laid out in cardinal directions to determine the 11.3 m radius tree-sampling circle were also used to measure vertical foliage distribution (Fig. 27). Starting from the center point, an additional five points, spaced 2.2 m apart (denoted by hash marks in Fig. 27) were sampled in each of the four directions. Foliage distribution was noted at six different height intervals: 0.5 - 3 m, 3 - 6 m, 6 - 12 m, 12 - 18 m, 18 - 24 m, and > 24 m. At each of these intervals foliage was reported as present (and given a value of one) or absent (and given a value of zero).

Statistical Analysis

Chi-square tests were run on HOWA territory occurrence and age class data to determine if significant differences existed between observed and expected values across plot types. A Kruskal-Wallis and one-way ANOVA were run to determine if significant differences existed between mean territory area in each plot type, and a Welch's *t*-test was run to determine if significant differences existed between territory areas in Japanese Barberry-dominated plots and plots containing substantial native understory (transitional and native understory-dominated plots collectively).

With regard to vegetation analysis data, a Chi-Square test was performed on sapling density data to determine if density was significantly different between the three plot types. Chi-Square tests were also run to determine if significant differences existed between presence of canopy gaps in use and available surveys. For shrub height, understory density, and canopy coverage data, Kruskal-Wallis tests were run to reveal significant differences between plot types, and Mann-Whitney U tests were run to reveal significant differences between use and available surveys within each plot type.

Finally, a Binary Logistic Regression was run to determine which vegetation characteristics (predictor variables) were most responsible for the presence or absence of HOWA (response variable) in study areas. The predictors were percentage of Japanese Barberry coverage, percentage of native understory species coverage, sapling density, shrub height, mean percent of canopy coverage, and mean understory density percentage. The response variable was HOWA territory presence (use surveys) or absence (available surveys) in a vegetation survey area. All Chi-Square tests were calculated using Microsoft Excel 2013® (Redmond, WA), and all other statistics were calculated using IBM SPSS Statistics 23® (Armonk, NY; 2015).

CHAPTER III

Results and Analysis

Hooded Warbler

Territory Occurrence:

Of the ten plots in each plot type, nine Japanese Barberry-dominated plots were occupied by at least one HOWA territory over the two field seasons, while seven of the transitional plots, and four of the native understory-dominated plots contained territories. Overall, 49 HOWA territories were located in the 30 study plots; 27 were found in the 2016 field season, and 22 in the 2017 field season. Twenty-two of these 49 territories were located in Japanese Barberry-dominated plots (10 in 2016 and 12 in 2017), 19 were located in transitional plots (11 in 2016 and eight in 2017), and eight were located in native understory-dominated plots (six in 2016 and two in 2017). A Chi-square test indicated a significant difference between observed HOWA territorial occurrence and expected frequencies across the three plot types during both field seasons ($\chi^2 = 6.67$, $df = 2$, $p = 0.0356$). When analyzed individually, 2017 territory

occurrence data was significant ($\chi^2 = 6.91$, $df = 2$, $p = 0.0316$), while 2016 territory occurrence data was not ($\chi^2 = 1.56$, $df = 2$, $p = 0.458$). When comparing the two plot types containing prevalent Japanese Barberry (Japanese Barberry-dominated and transitional plots collectively) to native plots, a Chi-square test indicated a significant difference between HOWA territory occurrence relative to the presence or absence of substantial amounts of Japanese Barberry ($\chi^2 = 22.22$, $df = 1$, $p < 0.01$). The proportions of HOWA territory occurrence in each plot type by field season are illustrated below (Fig. 28-29). A comparison of these proportions between the three plot types and between Japanese Barberry/transitional plots collectively and native understory-dominated plots is illustrated in figures 30-31. GPS coordinates for all territories can be found in Appendix IV.

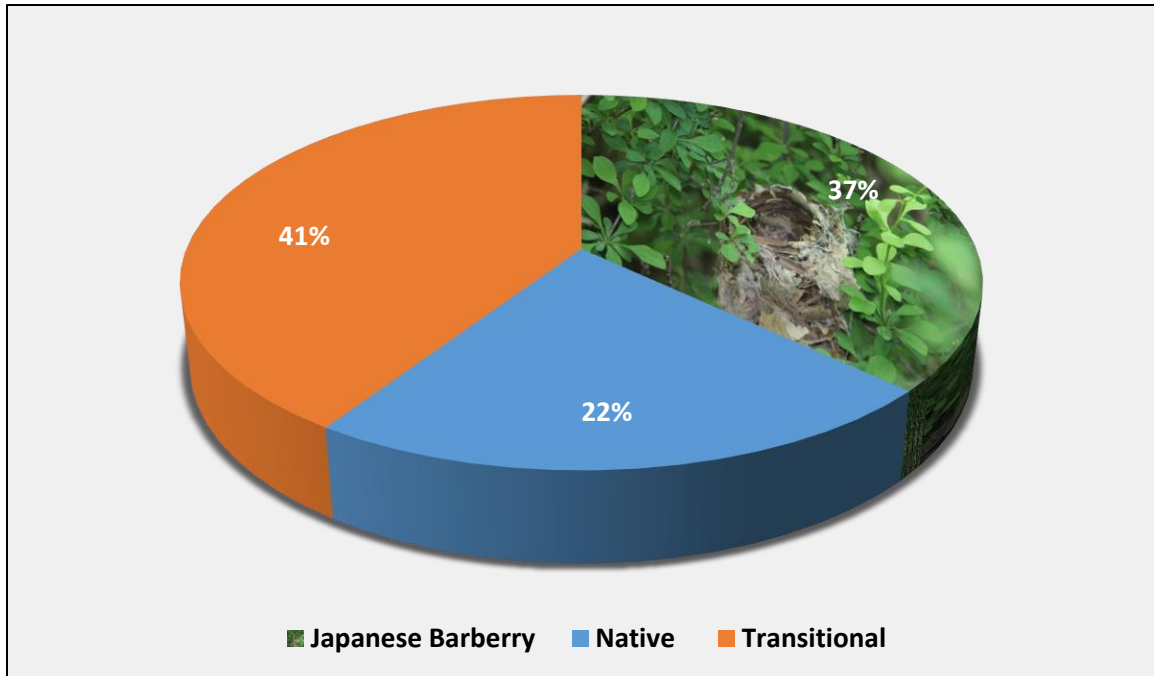


Figure 28. Proportions of HOWA territory occurrence in each of the three study plot types in the 2016 field season.

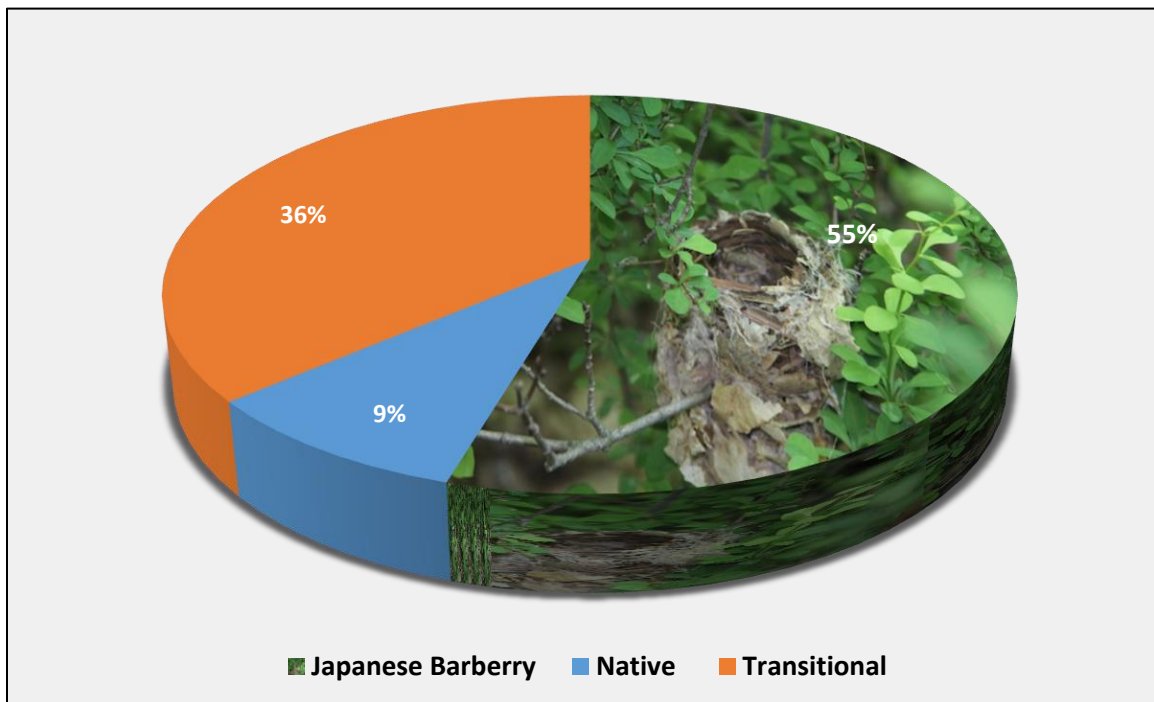


Figure 29. Proportions of HOWA territory occurrence in each of the three study plot types in the 2017 field season.

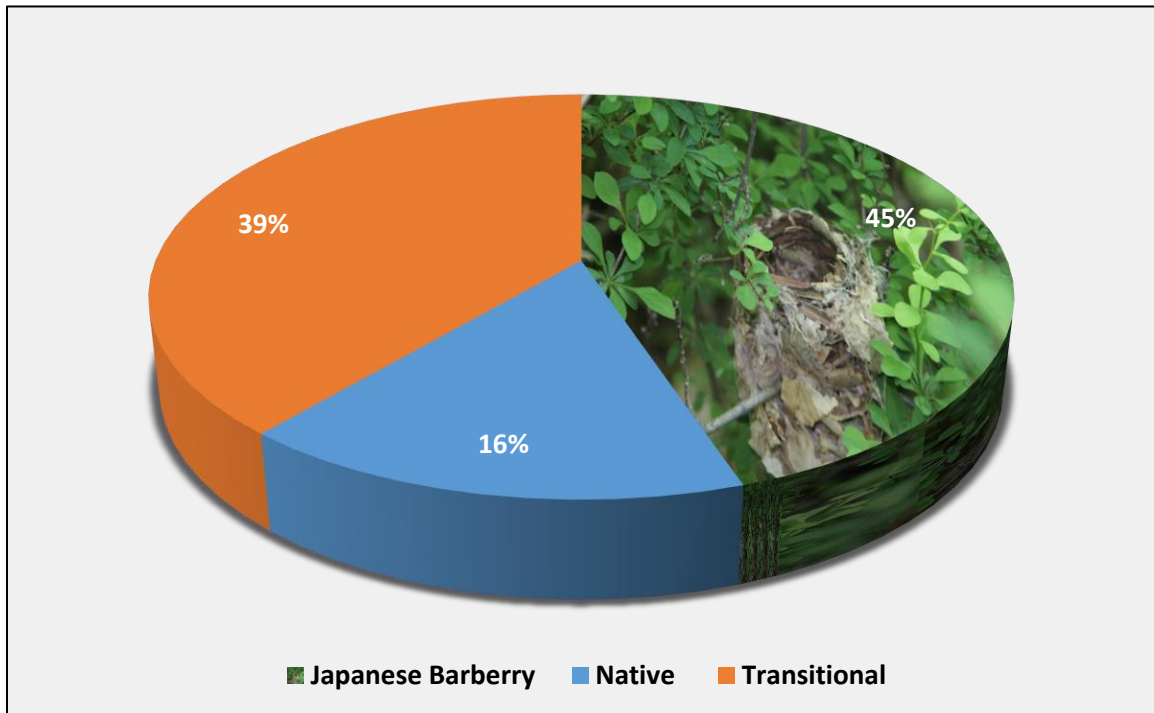


Figure 30. Proportions of HOWA territory occurrence for 2016-2017 across all three plot types.

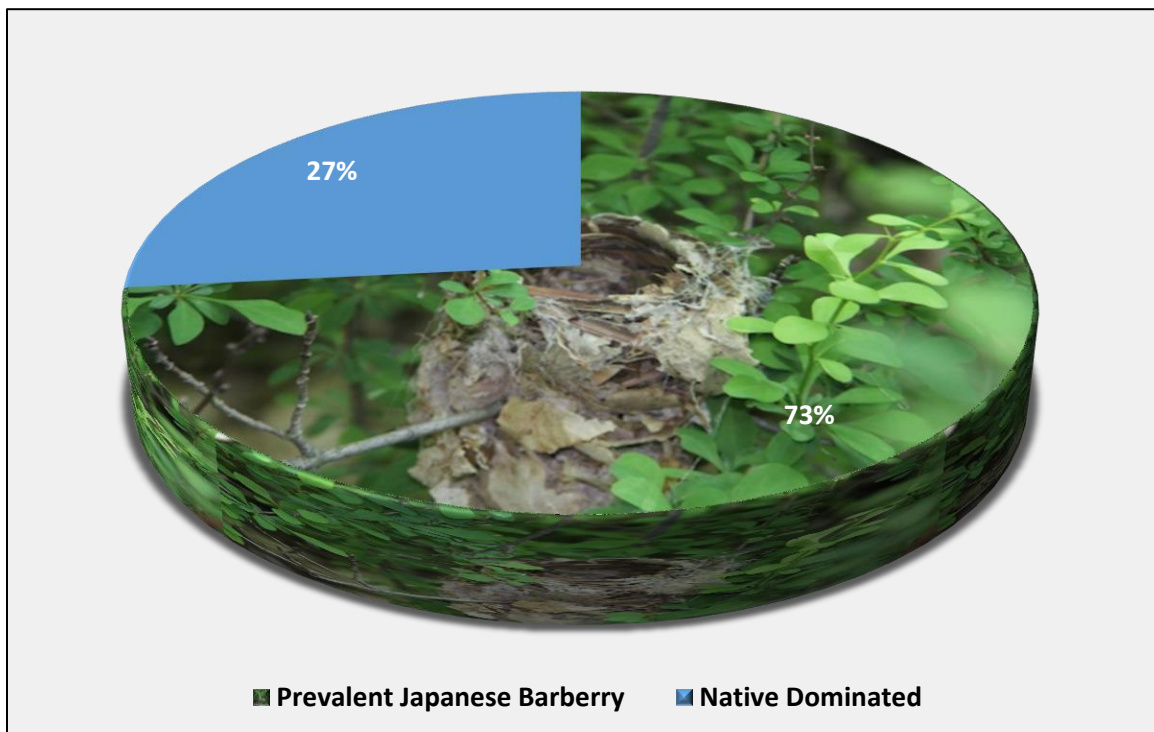


Figure 31. Proportions of HOWA territory occurrence for 2016-2017 between Japanese Barberry- dominated/transitional plots collectively and native understory-dominated plots.

Age Classes and Fidelity

During this study 41 HOWA were banded. In 2016 27 males (males of every territory located) and one female were banded, and in 2017 ten additional males and three additional females were banded. Thirty-nine of the 41 banded birds were successfully aged as SY (Second Year) or ASY (After Second Year), while the remaining two were non-juveniles of unknown age and were assigned the age-class AHY (After Hatch Year). Age-class by plot type of the 41 banded HOWA can be seen in Table 1. Plots with substantial amounts of Japanese Barberry (Japanese Barberry-dominated and transitional plots) had 28 ASY birds and 10 SY birds, while Native understory-dominated plots had five SY birds and three ASY birds. A Chi-square test indicated a significant difference between observed and expected ASY HOWA occurrence in the three plot types ($\chi^2 = 8.49$, $df = 2$, $p = 0.014$). Occurrence of SY birds was not significantly different from expected frequencies across the three plot types ($\chi^2 = 0.4$, $df = 2$, $p = 0.8$). Figure 32 shows the proportion of ASY birds in each plot type.

Of the 28 HOWA banded in 2016, seven were observed on study plots in 2017 and one was sighted just outside of the study plot in which it was banded. Overall, site fidelity was 28.6%. Six of the eight returning HOWA occupied the same habitat type as the previous year, with five of them occupying the same habitat plot as the previous year. The individual that returned to a location outside of the study plot occupied nearly identical habitat. All returning birds occupied the same 2x2 km study block as in the previous breeding season. Of the two HOWA that were not faithful to their habitat

types, both moved from native to transitional habitat plots. None of the returning birds moved to native habitat plots (Fig. 33). See Appendix V for banding data.

Table 1. HOWA age class by plot type, for 2016-2017.

Age Class	Japanese Barberry	Native	Transitional
ASY	13	3	15
SY	6	5	4
AHY	1	0	1

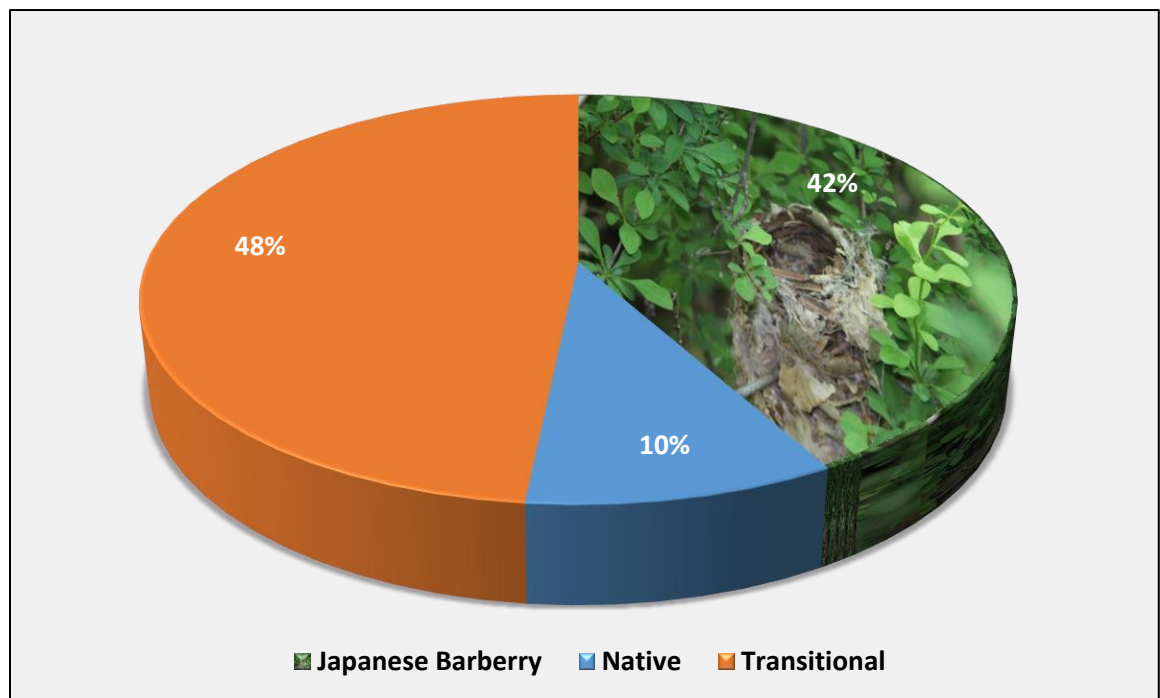


Figure 32. Proportions of ASY birds occurring across the three habitat plot types for 2016-2017.

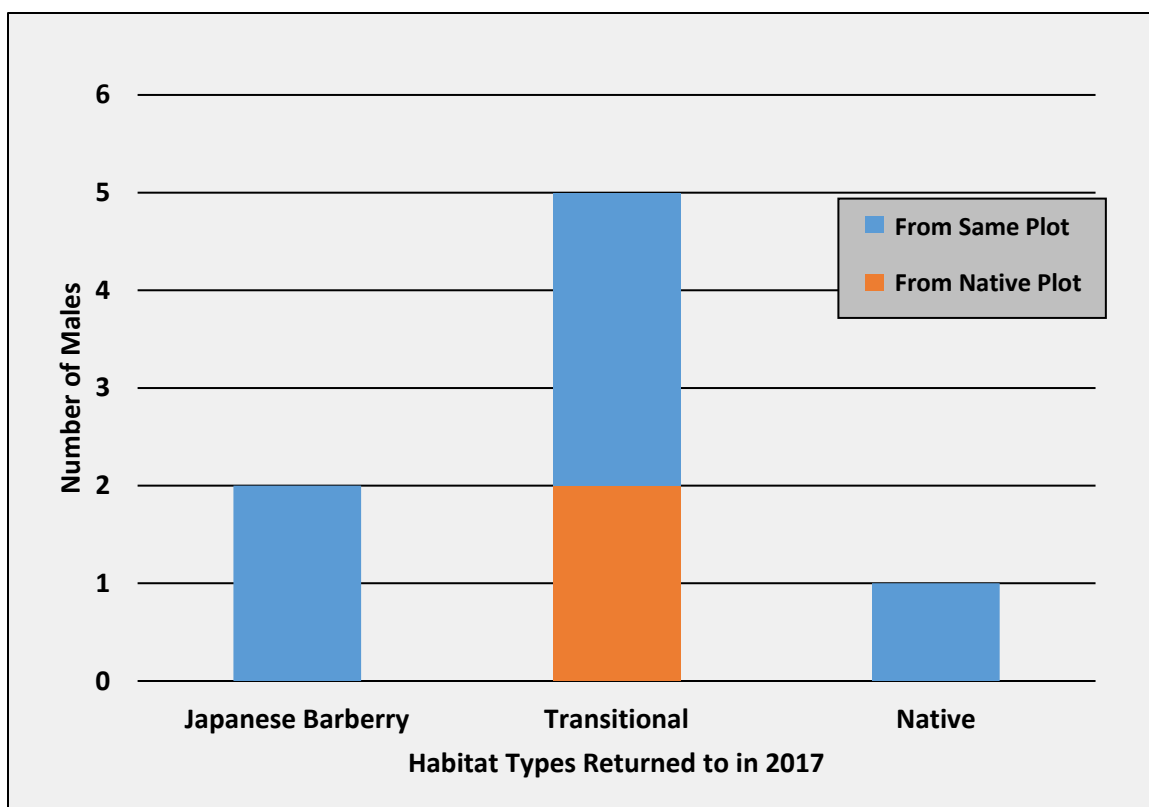


Figure 33. HOWA site fidelity between 2016 and 2017 field seasons by understory habitat type (including the individual that returned to the same habitat type outside of plot boundaries). Orange represents birds that moved from native understory-dominated plots.

Nesting Success

Locating nests proved very difficult, and only two nests were located in the study plots. The first was discovered in the Japanese Barberry-dominated plot of block nine on May 24, 2016, and the second nest was found in the Japanese Barberry-dominated plot of block three on May 18, 2017. Both nests were built in Japanese Barberry shrubs. The nest found in 2016 was parasitized by BHCO shortly after the nest was built and before any HOWA eggs were laid, causing the female to abandon the nest. The nest found in 2017 contained 4 eggs which all hatched, but it was predated and completely

lost on June 13, when the nestlings were approximately one week old. A third nest was found incidentally outside of the native understory-dominated plot of block four, constructed in grape vine (*Vitis* sp.). Although not formally part of this study, this nest was monitored casually. This nest was parasitized, but the female HOWA removed the foreign egg (likely laid by a Yellow-billed Cuckoo). It was predated and lost approximately one week after eggs were laid. Reproductive success could not be analyzed due to this small sample size. See Appendix VI for GPS coordinates of nests.

Territory Area

Territory area was calculated for all 49 territories using the “aggregate points” tool in ArcMap®. Overall, mean HOWA territory area in this study was found to be 0.251 ha. A Kruskal-Wallis test revealed that there was no significant difference between territory area in Japanese Barberry-dominated ($\bar{x} = 0.336$ ha), transitional ($\bar{x} = 0.165$ ha), and native ($\bar{x} = 0.198$ ha) dominated understory plots ($\chi^2 = 3.069$, $p = 0.216$). A one-way ANOVA also yielded non-significant results ($F = 1.837$, $p = 0.171$). When comparing plots that lacked any substantial amount of native understory plants (Japanese Barberry-dominated plots) to those that contained more substantial native understory plants (native-dominated and transitional plots), mean territory area was noticeably larger in plots mostly devoid of native shrubs and saplings ($\bar{x} = 0.336$ vs. 0.174 ha respectively) (Fig. 34). The results however were not significant (Welch’s T-test; $t = 3.03$, $p = 0.095$). It should be noted that due to time constraints, fewer territory

coordinates were taken than recommended over a shorter period of time than recommended for estimating Parulid territory areas (Barg et al. 2005).

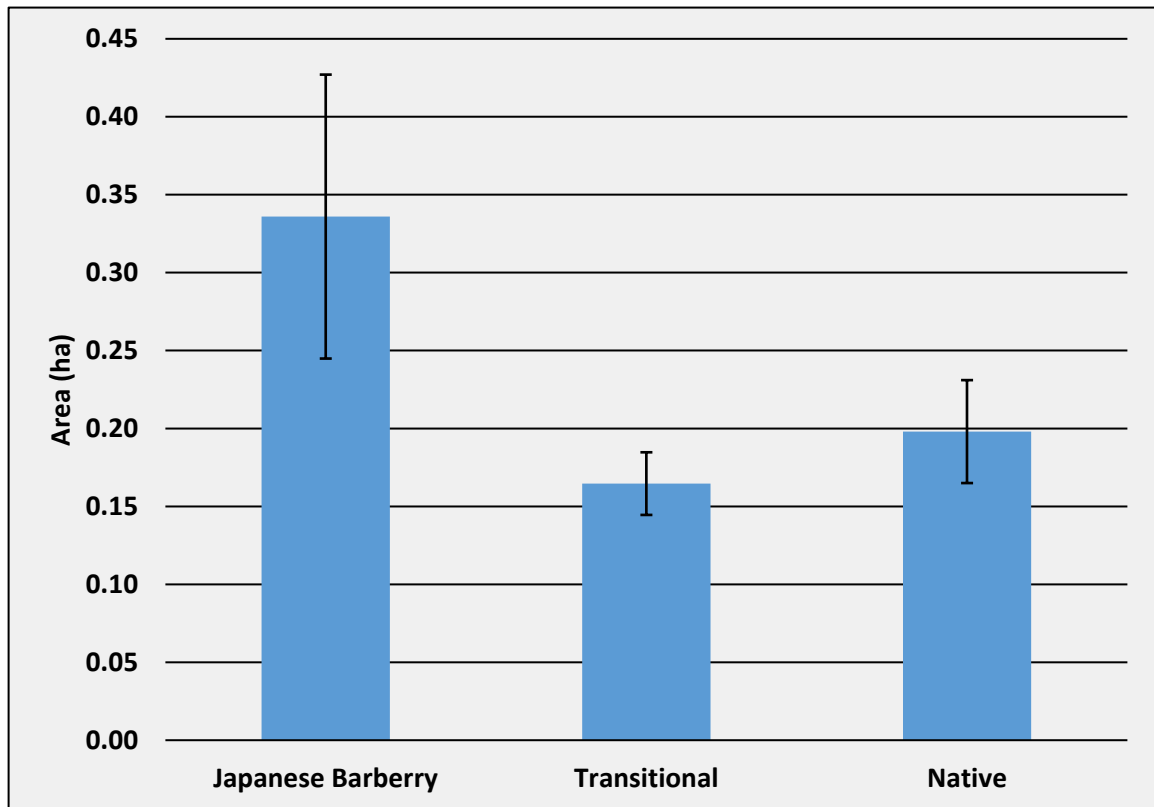


Figure 34. Mean area of HOWA territories by plot type for 2016-2017.

Pairing Success

Although pairs were observed more in Japanese Barberry-dominated plots, females were very difficult to locate so the pairing success of many males was uncertain (Table 2). Thus, pairing success was not analyzed statistically and should be viewed with caution.

Table 2. Pairs observed by habitat plot type for 2016-2017.

Habitat Plot	Paired	Uncertain
Japanese Barberry	14	8
Native	2	6
Transitional	9	11

Vegetation Analysis

Tree Analysis

Ecological Importance Values (IVs) were calculated for all trees in each of the three plot types, both in use and available surveys, and for all surveys across each plot type. Overall, Sugar Maple was the most common tree across all study plots, with the highest IV Percentage (26.45%) of all species present, and it represented 283 of the 969 trees measured. In Japanese Barberry-dominated plots, Sugar Maple was extremely common, representing 172 of 334 trees (51.5%) measured. Tables 3-5 show ecological importance values for trees in all survey areas of Japanese Barberry-dominated, transitional, and native understory-dominated plots, respectively, that had ecological importance percentages greater than three percent. Complete IVs for all tree species

present can be found in Appendix VII. Differences in tree analysis data between use and available surveys were not analyzed, as understory species composition is more important to breeding HOWA than canopy species composition (Chiver et al. 2011).

Table 3. Tree species with an ecological importance percentage > 3% in all vegetation surveys of Japanese Barberry-dominated plots.

Tree Species	Relative Density	Relative Dominance	Relative Frequency	IV	IV Percent
Sugar Maple	0.51	0.55	0.21	1.28	42.56
Green Ash	0.06	0.04	0.09	0.19	6.48
White Ash	0.05	0.06	0.08	0.18	6.14
Black Walnut	0.05	0.05	0.06	0.16	5.40
Eastern Hemlock	0.03	0.05	0.08	0.16	5.21
Black Birch	0.04	0.03	0.05	0.12	3.95
Northern Red Oak	0.02	0.03	0.06	0.11	3.55
Black Locust	0.04	0.04	0.02	0.10	3.48

Table 4. Tree species with an ecological importance percentage > 3% in all vegetation surveys of transitional plots.

Tree Species	Relative Density	Relative Dominance	Relative Frequency	IV	IV Percent
Sugar Maple	0.24	0.21	0.15	0.61	20.18
Black Birch	0.22	0.18	0.12	0.51	17.08
Northern Red Oak	0.11	0.13	0.13	0.37	12.37
Red Maple	0.08	0.09	0.08	0.25	8.17
White Oak	0.05	0.04	0.07	0.16	5.18
Black Cherry	0.04	0.06	0.05	0.15	4.99
Green Ash	0.03	0.03	0.04	0.10	3.36
Eastern Hemlock	0.04	0.03	0.03	0.10	3.36

Table 5. Tree species with an ecological importance percentage > 3% in all vegetation surveys of native understory-dominated plots.

Tree Species	Relative Density	Relative Dominance	Relative Frequency	IV	IV Percent
Eastern Hemlock	0.19	0.16	0.08	0.42	14.12
Black Birch	0.14	0.16	0.09	0.39	12.94
Sugar Maple	0.11	0.12	0.11	0.34	11.37
Northern Red Oak	0.09	0.09	0.10	0.29	9.54
Red Maple	0.07	0.10	0.08	0.24	8.12
Black Cherry	0.04	0.04	0.09	0.17	5.67
Eastern Red Cedar	0.05	0.04	0.05	0.13	4.48
Scrub Oak	0.05	0.03	0.04	0.11	3.78
White Oak	0.03	0.04	0.04	0.10	3.42

Sapling Analysis

Saplings were more commonly observed in transitional plots and native understory-dominated plots than those with understory-dominated by Japanese Barberry. Overall, transitional plots contained 275 saplings (170 in use surveys and 105 in available surveys), native understory-dominated plots contained 152 saplings (47 in use surveys and 105 in available surveys), and Japanese Barberry-dominated plots contained 107 saplings (56 in use surveys and 51 in available surveys). A Chi Square indicated that sapling density was significantly different between the three plot types ($\chi^2 = 86.13$, $df = 2$, $p < 0.00001$).

As was done to analyze trees, IVs were calculated for saplings in all three plot types, both in use and available surveys and in all surveys of each plot type. Tables 6-8 show ecological importance values for saplings in all survey areas of Japanese Barberry-dominated, transitional, and native understory-dominated plots, respectively, that had ecological importance percentages of greater than three percent. Note that native-dominated plots had the highest number of ecologically important sapling species. Complete IVs for all sapling species present can be found in Appendix VIII.

Preference and avoidance values were calculated for HOWA territories by subtracting available survey IVs from use survey IVs. If the resulting numbers from these calculations were positive, this indicated a “preference” as these sapling species occurred more frequently in use plots than expected based on availability within random available plots. If these calculations resulted in negative numbers, this

represented an “avoidance” as these species occurred less often in territories (use plots) than would be expected. The following preference/avoidance graphs show these results for sapling species with greater than three percent IVs in each of the three plot types (Fig. 35-37).

Table 6. Sapling species with an ecological importance percentage > 3% in all vegetation surveys of Japanese Barberry-dominated plots.

Sapling Species	Relative Density	Relative Dominance	Relative Frequency	IV	IV Percent
Black Walnut	0.29	0.20	0.10	0.59	19.74
Sugar Maple	0.14	0.18	0.10	0.42	13.99
Yellow Birch	0.09	0.12	0.07	0.28	9.17
American Hornbeam	0.05	0.11	0.10	0.26	8.65
American Beech	0.08	0.05	0.10	0.24	7.88
Black Cherry	0.07	0.05	0.07	0.18	6.05
Black Birch	0.05	0.04	0.07	0.15	4.95
Black Tupelo	0.06	0.06	0.03	0.15	4.92
Tulip Poplar	0.05	0.02	0.07	0.13	4.31

Table 7. Sapling species with an ecological importance percentage of > 3% in all vegetation surveys of transitional plots.

Sapling Species	Relative Density	Relative Dominance	Relative Frequency	IV	IV Percent
Black Walnut	0.29	0.20	0.10	0.59	19.74
Black Birch	0.20	0.23	0.10	0.53	17.54
American Beech	0.14	0.14	0.16	0.44	14.51
White Oak	0.16	0.10	0.07	0.34	11.19
Sugar Maple	0.10	0.10	0.11	0.31	10.35
White Pine	0.08	0.11	0.06	0.25	8.18
Black Cherry	0.06	0.06	0.07	0.20	6.57
Northern Red Oak	0.03	0.04	0.06	0.13	4.41
Eastern Hemlock	0.03	0.03	0.06	0.12	3.94
American Hornbeam	0.03	0.04	0.04	0.10	3.44
Sassafras	0.04	0.02	0.05	0.10	3.34

Table 8. Sapling species with an ecological importance percentage of > 3% in all vegetation surveys of native-dominated understory plots.

Sapling Species	Relative Density	Relative Dominance	Relative Frequency	IV	IV Percent
Black Birch	0.22	0.28	0.09	0.59	19.58
American Beech	0.17	0.22	0.15	0.53	17.83
Black Cherry	0.14	0.09	0.11	0.34	11.26
Tulip Poplar	0.07	0.06	0.11	0.25	8.25
Eastern Hemlock	0.06	0.14	0.02	0.22	7.34
Flowering Dogwood	0.02	0.11	0.04	0.17	5.51
Sugar Maple	0.05	0.06	0.06	0.16	5.39
Scrub Oak	0.05	0.06	0.04	0.15	5.01
White Pine	0.03	0.10	0.02	0.14	4.73
American Hornbeam	0.02	0.07	0.04	0.13	4.28
Northern Red Oak	0.03	0.05	0.04	0.11	3.83
Mockernut Hickory	0.05	0.03	0.02	0.10	3.46

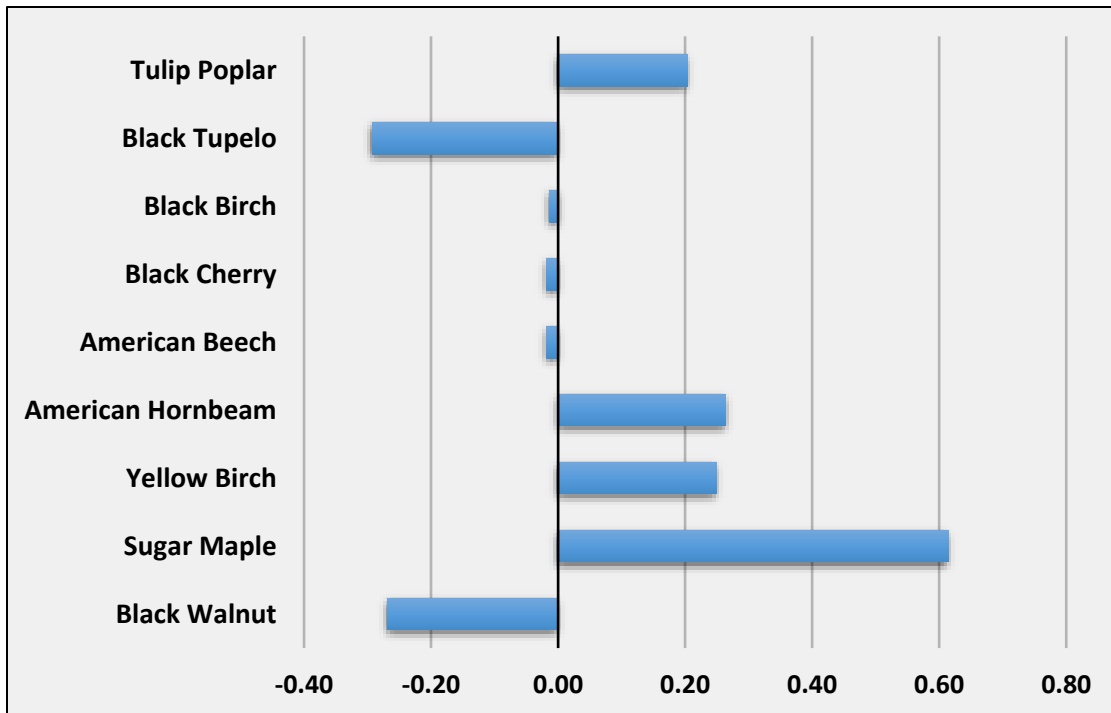


Figure 35. Preference/avoidance values derived from IVs of sapling species located in Japanese Barberry-dominated understory study plots. Positive values indicate HOWA preference and negative values indicate avoidance.

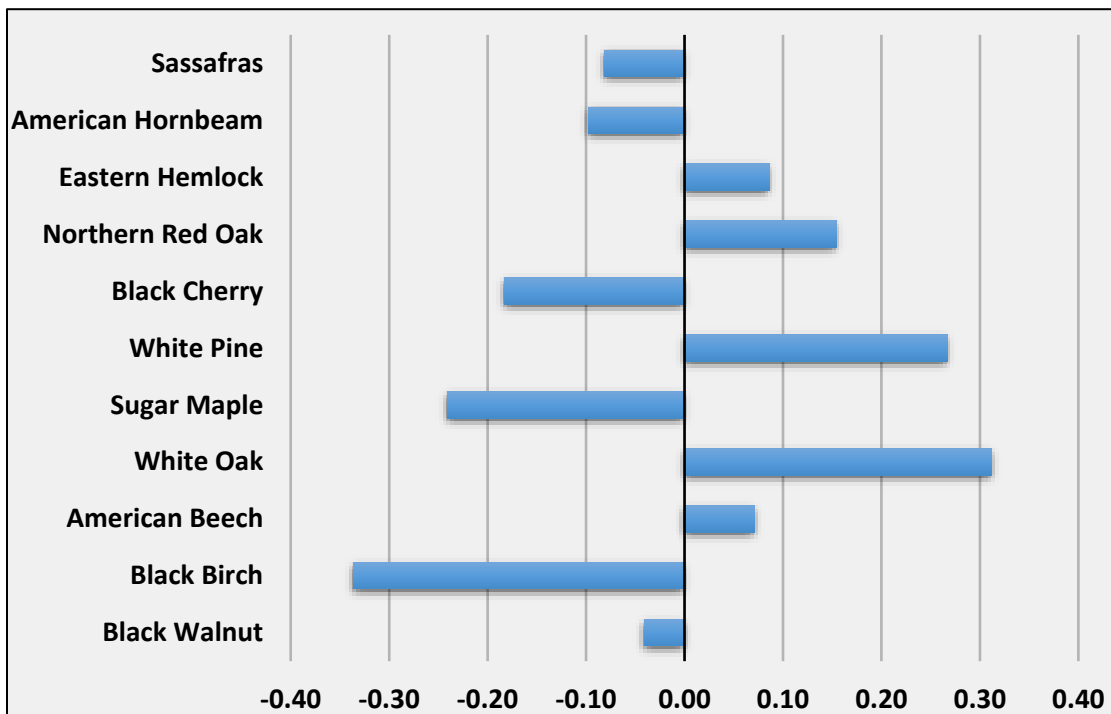


Figure 36. Preference/avoidance values derived from IVs of sapling species located in transitional understory study plots. Positive values indicate HOWA preference and negative values indicate avoidance.

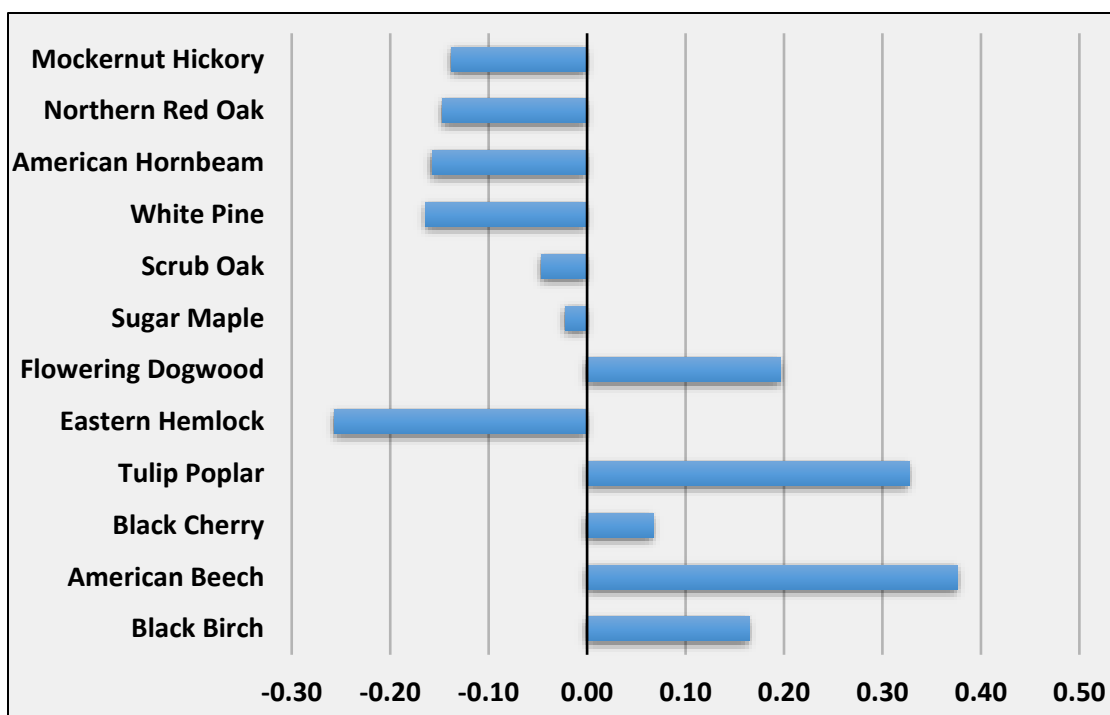


Figure 37. Preference/avoidance values derived from IVs of sapling species located in native understory-dominated study plots. Positive values indicate HOWA preference and negative values indicate avoidance.

Shrub Analysis

Spicebush was codominant with Japanese Barberry in transitional plots, and with Lowbush Blueberry (*Vaccinium angustifolium*) in native understory-dominated plots. Out of 32 surveys performed in Japanese Barberry-dominated plots, 29 (90.1%) had Japanese Barberry as their dominant shrub species, and only one survey had a native shrub species (Northern Dewberry) as a dominant shrub species. Of 25 surveys in transitional plots, Japanese Barberry was the dominant shrub species in nine of them (36%), and a native shrub species (Spicebush, Blueberry, or Northern Dewberry) was the most dominant shrub species in 14 surveys (56%) (the remaining two surveys were dominated by saplings rather than shrubs). Finally, out of 17 surveys in native

understory-dominated plots, 15 (88.2%) featured a native shrub species (Spicebush, Blueberry, Mountain Laurel, Rosebay Rhododendron, or Northern Dewberry) as their most dominant shrub, with the remaining two surveys being dominated by native saplings. Japanese Barberry was present to some degree in all 32 Japanese Barberry-dominated plot surveys (100%; 22 use and 10 available surveys), 22 transitional surveys (88% of the 25 total; 15 use and 7 available surveys), and 6 native understory-dominated surveys (35.3% of the 17 total; 3 use and 3 available surveys).

Ecological Importance Values were again calculated for shrubs in all three plot types; both in use and available surveys and across all surveys of each plot type. A modified protocol for calculating IVs of shrubs was used, as described in Chapter II: Methods. Tables 9-11 show ecological importance values for shrubs in all survey areas of Japanese Barberry-dominated, transitional, and native understory-dominated plots, respectively, which had ecological importance percentages of greater than three percent. Note that Japanese Barberry-dominated plots contained fewer ecologically important shrub species than other plot types. Complete IVs for all shrub species present can be found in Appendix IX.

As with saplings, shrub preference/avoidance values were calculated for HOWA territories by subtracting available survey IVs from use survey IVs. Positive values indicated a preference for HOWA choosing territories containing a given shrub species and negative values indicated an avoidance. The following preference/avoidance graphs

show these results for shrub species with greater than three percent IVs in each of the three plot types (Fig. 38-40).

Shrub height was analyzed across all three plot types and in use and available surveys of each plot type. A Kruskal-Wallis test revealed no significant differences in shrub height between the three plot types ($\chi^2 = 0.144$, $p = 0.931$). A Mann-Whitney U test revealed that mean shrub height was significantly lower in use survey areas ($\bar{x} = 1.01$ m) than in random available survey areas ($\bar{x} = 1.36$) of Japanese Barberry-dominated understory plots ($U = 430$, $z = -2.024$, $p = 0.043$). However there was no significant difference between mean shrub height in use ($\bar{x} = 1.11$ m) vs. available surveys ($\bar{x} = 1.04$ m) within transitional understory plots ($U = 444$, $z = -0.233$, $p = 0.816$), nor was there any significant difference between the two ($\bar{x} = 1.14$ m and 1.45 m respectively) in native understory-dominated plots ($U = 135$, $z = -0.829$, $p = 0.407$). Figure 41 shows differences in average shrub height between the three plot types.

Table 9. Shrub species with an ecological importance percentage > 3% in all vegetation surveys of Japanese Barberry-dominated plots.

Shrub Species	Relative Density	Relative Coverage	IV	IV Percent
Japanese Barberry	0.44	0.82	1.26	63.15
Multiflora Rose	0.23	0.08	0.31	15.46
Spicebush	0.12	0.02	0.15	7.37
Autumn Olive	0.05	0.02	0.08	3.94
Japanese Wisteria	0.04	0.03	0.07	3.59

Table 10. Shrub species with an ecological importance percentage > 3% in all vegetation surveys of transitional plots.

Shrub Species	Relative Density	Relative Coverage	IV	IV Percent
Japanese Barberry	0.35	0.38	0.73	36.64
Spicebush	0.21	0.27	0.48	23.86
Highbush Blueberry	0.10	0.15	0.24	12.10
Multiflora Rose	0.11	0.03	0.14	6.92
Japanese Wisteria	0.03	0.08	0.11	5.59
Lowbush Blueberry	0.03	0.05	0.09	4.26
Burning Bush	0.06	0.01	0.07	3.44

Table 11. Shrub species with an ecological importance percentage > 3% in all vegetation surveys of native understory-dominated plots.

Shrub Species	Relative Density	Relative Coverage	IV	IV Percent
Spicebush	0.31	0.39	0.70	34.77
Lowbush Blueberry	0.19	0.28	0.48	23.89
Japanese Barberry	0.17	0.02	0.18	9.20
Autumn Olive	0.11	0.02	0.13	6.64
Mountain Laurel	0.06	0.08	0.14	6.85
Northern Dewberry	0.03	0.08	0.11	5.46
Rosebay Rhododendron	0.03	0.04	0.07	3.29

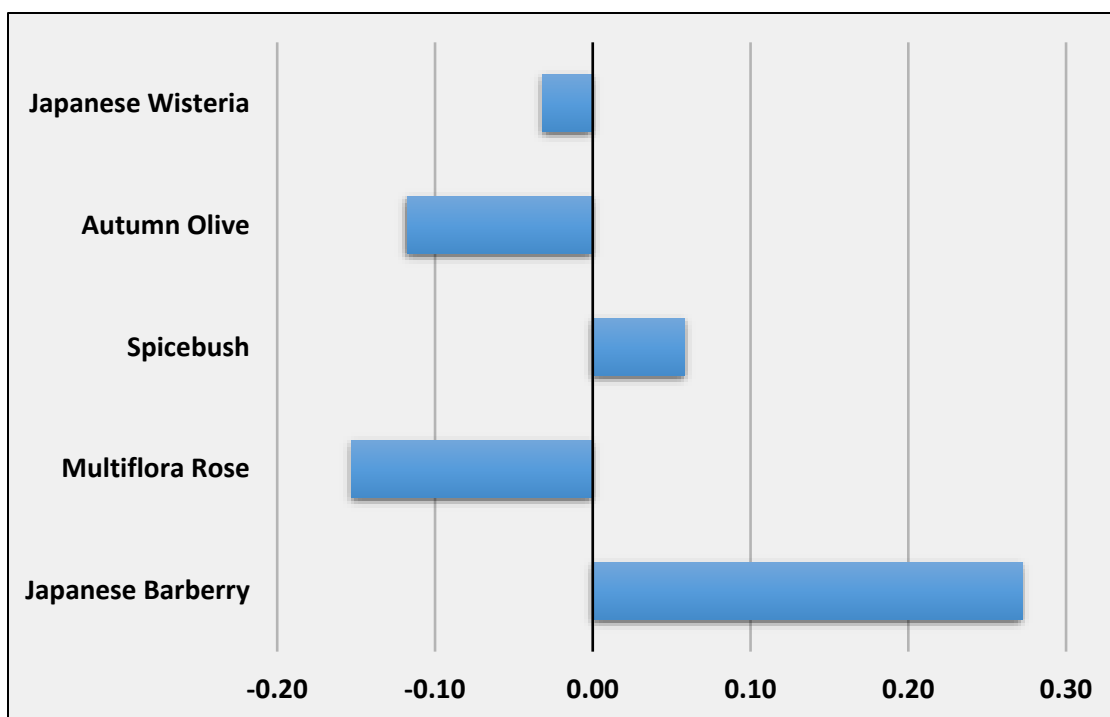


Figure 38. Preference/avoidance values derived from IVs of shrub species located in Japanese Barberry-dominated understory study plots. Positive values indicate HOWA preference and negative values indicate avoidance.

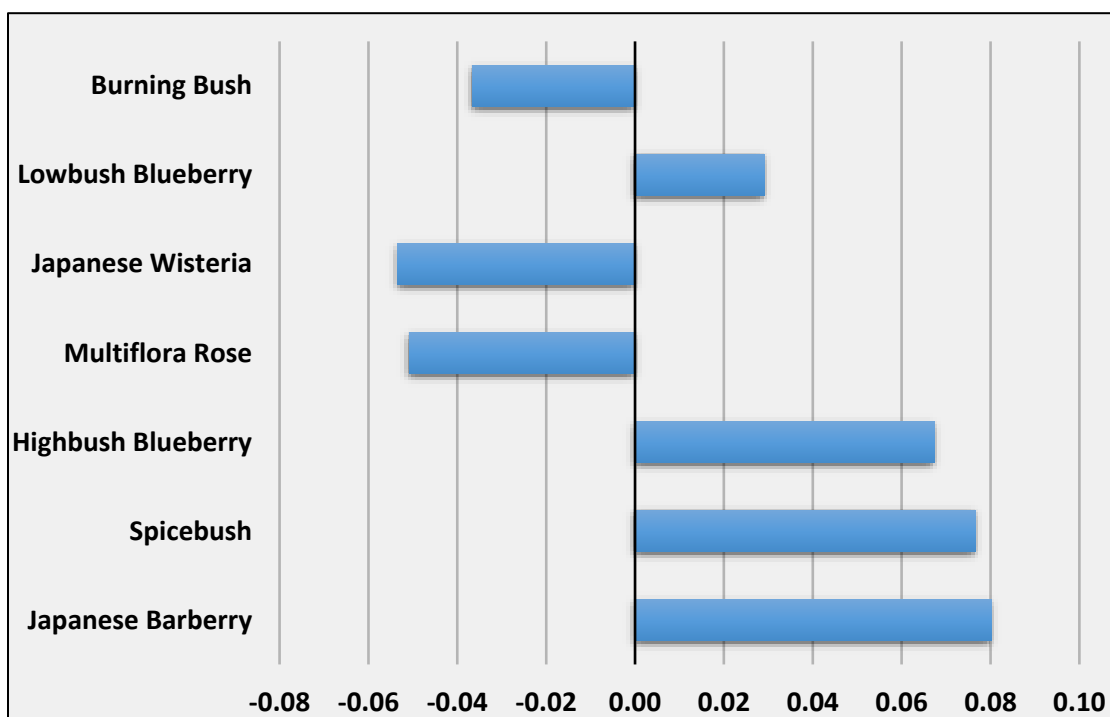


Figure 39. Preference/avoidance values derived from IVs of shrub species located in transitional understory study plots. Positive values indicate HOWA preference and negative values indicate avoidance.

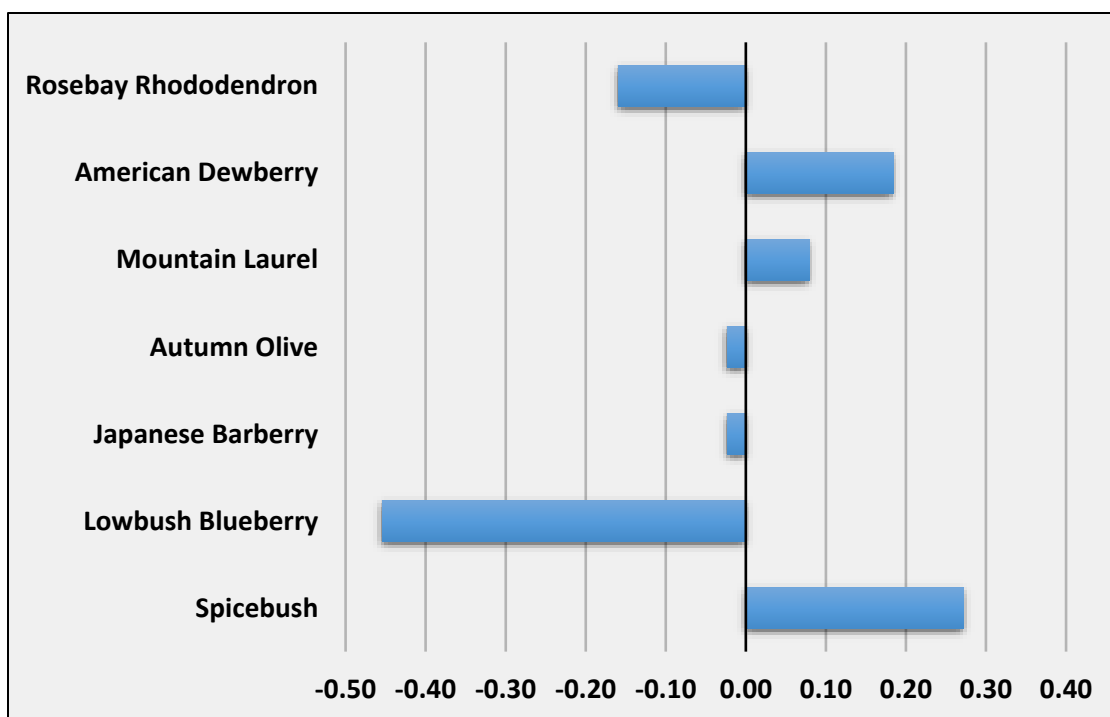


Figure 40. Preference/avoidance values derived from IVs of shrub species located in native understory-dominated study plots. Positive values indicate HOWA preference and negative values indicate avoidance.

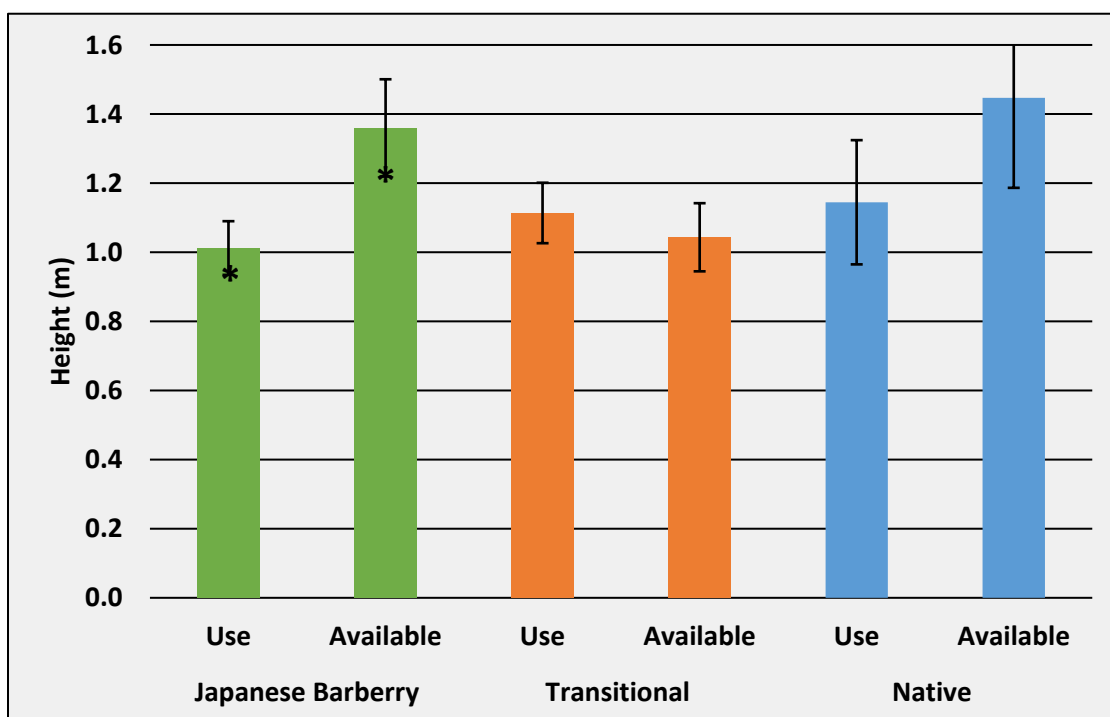


Figure 41. Mean shrub height for available and use surveys of each plot type. * indicates significant difference between shrub height in use and available surveys.

Understory Density

A Kruskal-Wallis test was done to analyze differences in understory density between the three plot types. Mean understory density was 81.88 percent in Japanese Barberry-dominated plots, 81.51% in transitional plots, and 76.12% in native understory-dominated plots. Although average density was higher in plots containing substantial amounts of Japanese Barberry (transitional and Japanese Barberry-dominated) than native understory-dominated plots, this does not represent a significant difference ($\chi^2 = 0.760$, $p = 0.684$).

Understory density was also analyzed within use and available survey areas of each plot type using Mann-Whitney U tests. Use vegetation surveys (those conducted in occupied territories) of Japanese Barberry plots had a significantly higher understory density ($\bar{x} = 87.91\%$) than random available vegetation surveys in this plot type ($\bar{x} = 68.6\%$) ($U = 68$, $z = -1.71$, $p = 0.047$). In Transitional plots, a similar pattern was seen with use surveys having significantly higher understory density ($\bar{x} = 92.93\%$) than random available survey areas ($\bar{x} = 64.39\%$) ($U = 18$, $z = -3.173$, $p = 0.002$). Finally, native understory-dominated plots also showed use territories with significantly higher shrub density percentages ($\bar{x} = 94.57\%$) than random available survey areas ($\bar{x} = 63.2\%$) ($U = 63.2$, $z = -2.63$, $p = 0.008$). Figure 42 shows understory density in available vs. use surveys of all plot types.

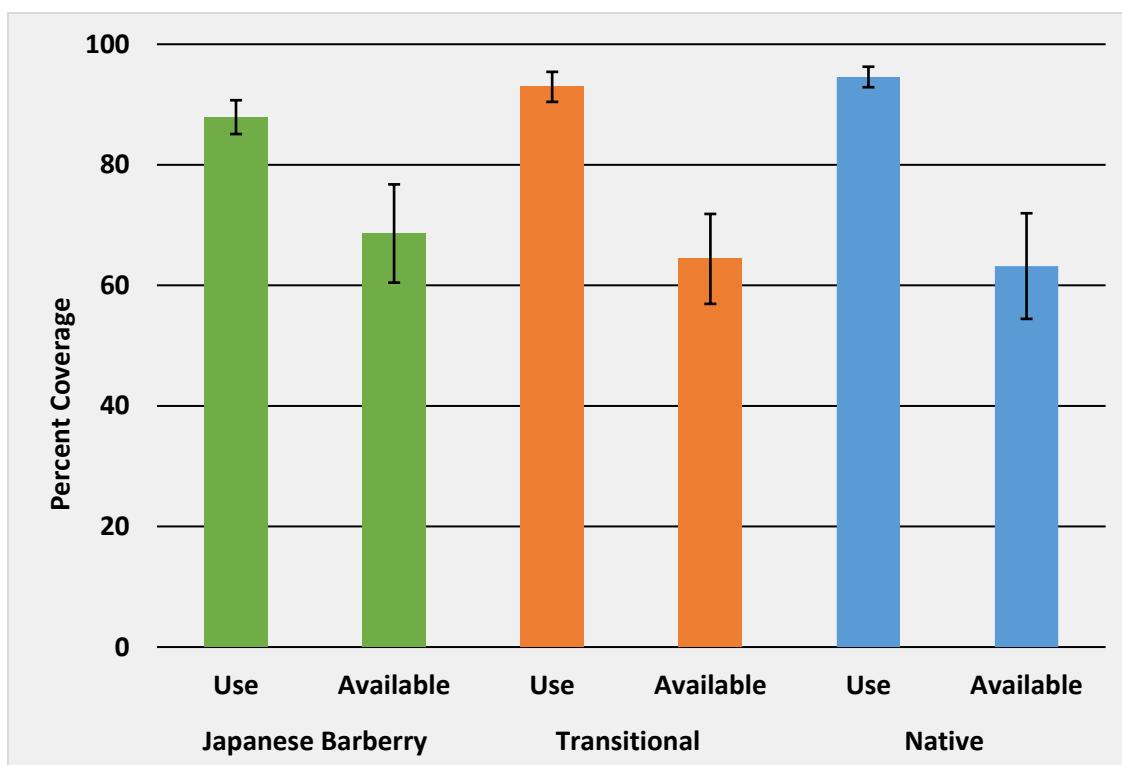


Figure 42. Mean understory density percentages within use and available vegetation survey areas by plot type. Available surveys had significantly lower understory density than use surveys in all plot types.

Foliage Height Distribution

For each height interval, foliage “hits” (foliage present) were given a value of one, and “misses” (foliage absent) were given a value of zero. These values were averaged for each height interval by plot type and for use vs. available surveys (Table 12). Use surveys in each of the three plot types averaged greater than 50 percent “hits” in the 0.5-3 m height interval, while available surveys in none of the three plot types averaged more than 50 percent hits in this interval. Native plots showed noticeably fewer “hits” in the 24+ m range than the other plot types, especially in available surveys, while Japanese Barberry-dominated plots showed noticeably more “hits” in the lowest

height interval than the other plot types. Overall, less hits were recorded in all surveys in the “mid-story” height intervals of 3-6 and 6-12 m, and more hits were recorded in the understory (0.5-3 m), and canopy (12 m and above). Figures 43-45 show mean foliage height distribution data (presence/absence) of each height interval for each plot type in use and random available territories.

Table 12. Mean Foliage Presence/Absence Values for Foliage Height Distribution Surveys.

Height Interval	Japanese Barberry			Transitional			Native Understory		
	Use	Available	All Surveys	Use	Available	All Surveys	Use	Available	All Surveys
0.5-3 m	0.54	0.46	0.50	0.61	0.42	0.51	0.71	0.50	0.61
3-6 m	0.32	0.33	0.32	0.50	0.38	0.44	0.45	0.48	0.46
6-12 m	0.50	0.41	0.46	0.59	0.52	0.55	0.40	0.55	0.47
12-18 m	0.71	0.52	0.61	0.64	0.66	0.65	0.63	0.74	0.68
18-24 m	0.82	0.61	0.72	0.69	0.63	0.66	0.66	0.59	0.63
24+ m	0.57	0.42	0.49	0.52	0.58	0.55	0.41	0.22	0.31

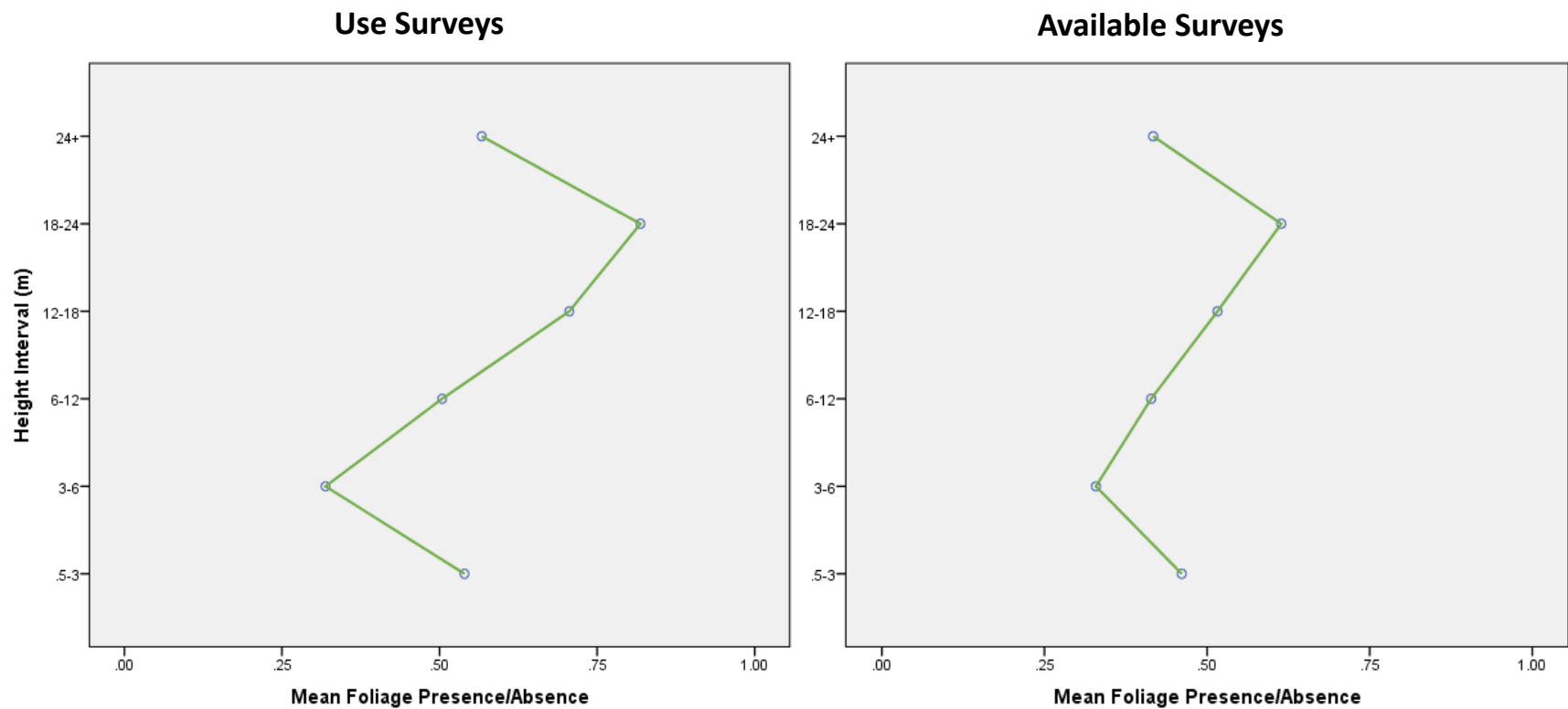


Figure 43. Foliage height distribution in use surveys (left) and available surveys (right) of Japanese Barberry-dominated plots. Y-axis shows the six height intervals in which foliage presence or absence was recorded. X-axis shows mean foliage presence in each height interval on a scale of 0-1.

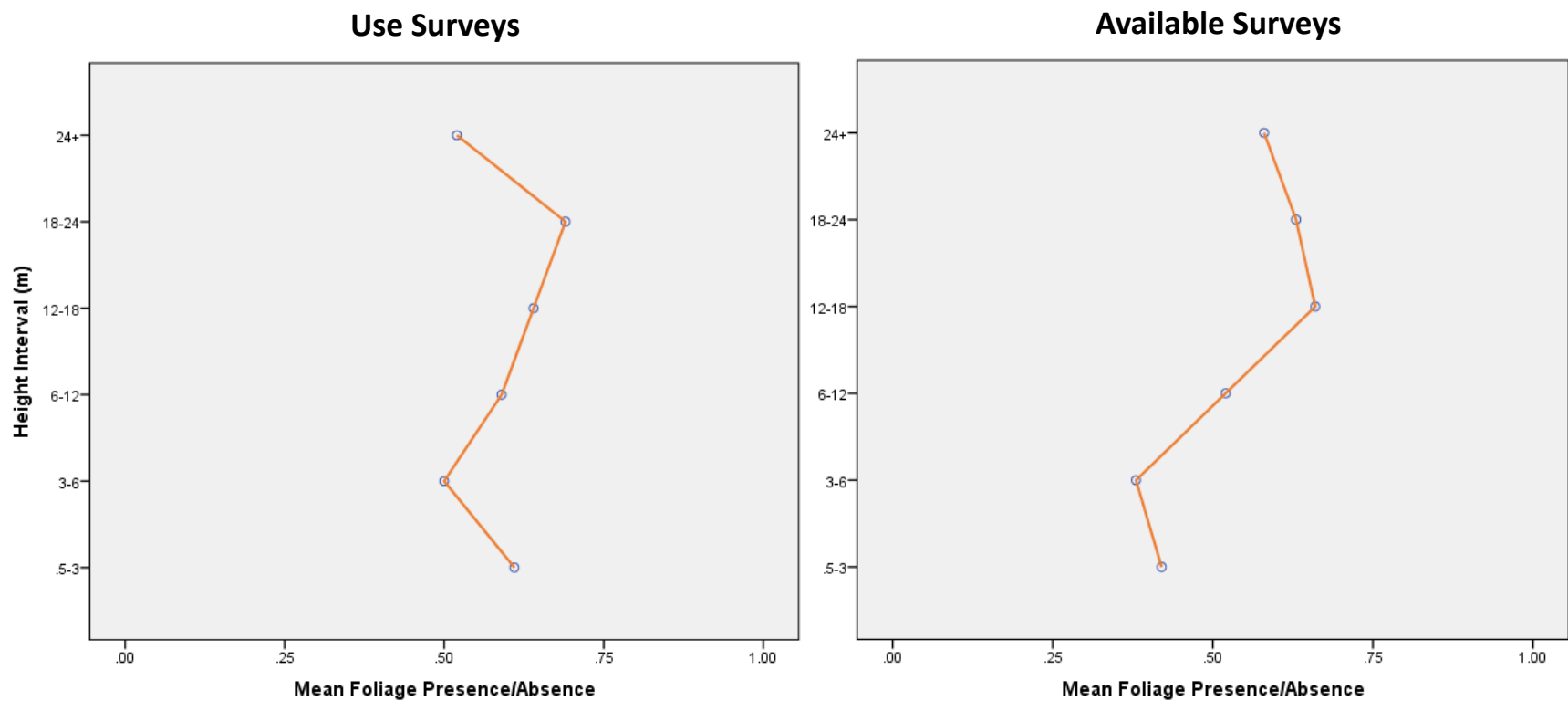


Figure 44. Foliage height distribution in use surveys (left) and available surveys (right) of transitional plots. Y-axis shows the six height intervals in which foliage presence or absence was recorded. X-axis shows mean foliage presence in each height interval on a scale of 0-1.

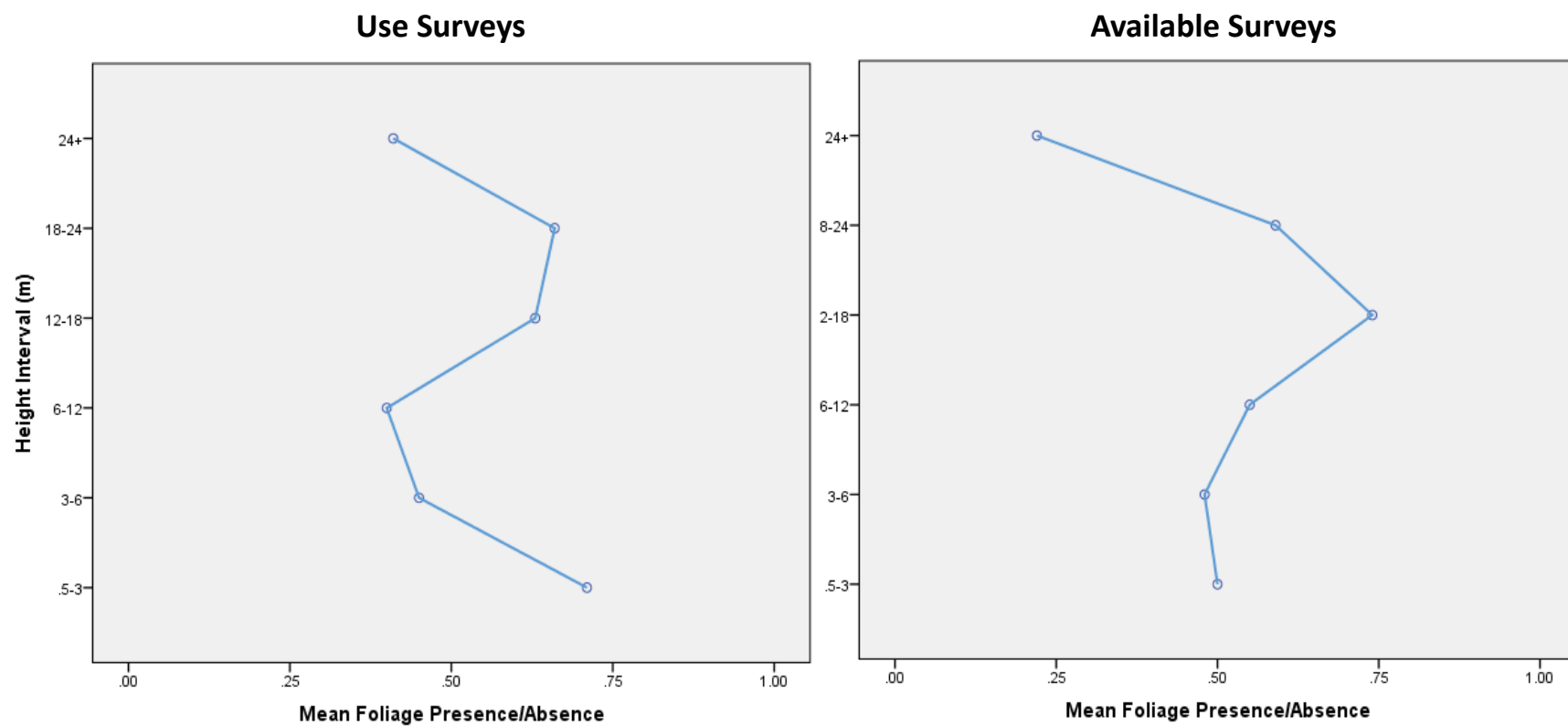


Figure 45. Foliage height distribution in use surveys (left) and available surveys (right) of native understory-dominated plots. Y-axis shows the six height intervals in which foliage presence or absence was recorded. X-axis shows mean foliage presence in each height interval on a scale of 0-1.

Canopy Coverage

A Kruskal-Wallis test revealed that mean canopy coverage was not significantly different between Japanese Barberry-dominated plots ($\bar{x} = 91.26\%$), transitional plots ($\bar{x} = 91.79\%$), and native understory-dominated plots ($\bar{x} = 89.3\%$) ($\chi^2 = 0.632$, $p = 0.730$).

Mann-Whitney U tests revealed no significant difference in canopy coverage between use ($\bar{x} = 92.53\%$) and random available survey areas ($\bar{x} = 88.48\%$) within Japanese Barberry-dominated understory plots ($U = 85.5$, $z = -0.997$, $p = 0.319$).

Likewise, there was no significant difference in canopy coverage between use ($\bar{x} = 91.92\%$) and random available survey areas ($\bar{x} = 91.59\%$) within transitional understory plots ($U = 67.5$, $z = -0.416$, $p = 0.677$). Finally, there was no significant difference in canopy coverage between use ($\bar{x} = 85.55\%$) and random available survey areas ($\bar{x} = 91.92\%$) within native understory-dominated plots ($U = 23$, $z = -1.171$, $p = 0.242$).

There was no significant difference in the occurrence of canopy openings between occupied and random available vegetation surveys, in Japanese Barberry-dominated, transitional, or native understory-dominated plots ($\chi^2 = 1.0$, 1.8 , and 1.0 ; $df = 1$, 1 , and 1 ; $p = 0.32$, 0.18 , and 0.32 respectively). Figure 46 shows densitometer readings of all surveys by plot type, sorted in descending order and plotted on a line graph. Sharp dips in the lines represent larger canopy gaps, and long depressions in the lines represent more frequent openings. While all plot types showed canopy gaps, the largest gaps were observed in native understory-dominated plots, and the most frequent gaps were observed in Japanese Barberry-dominated plots.

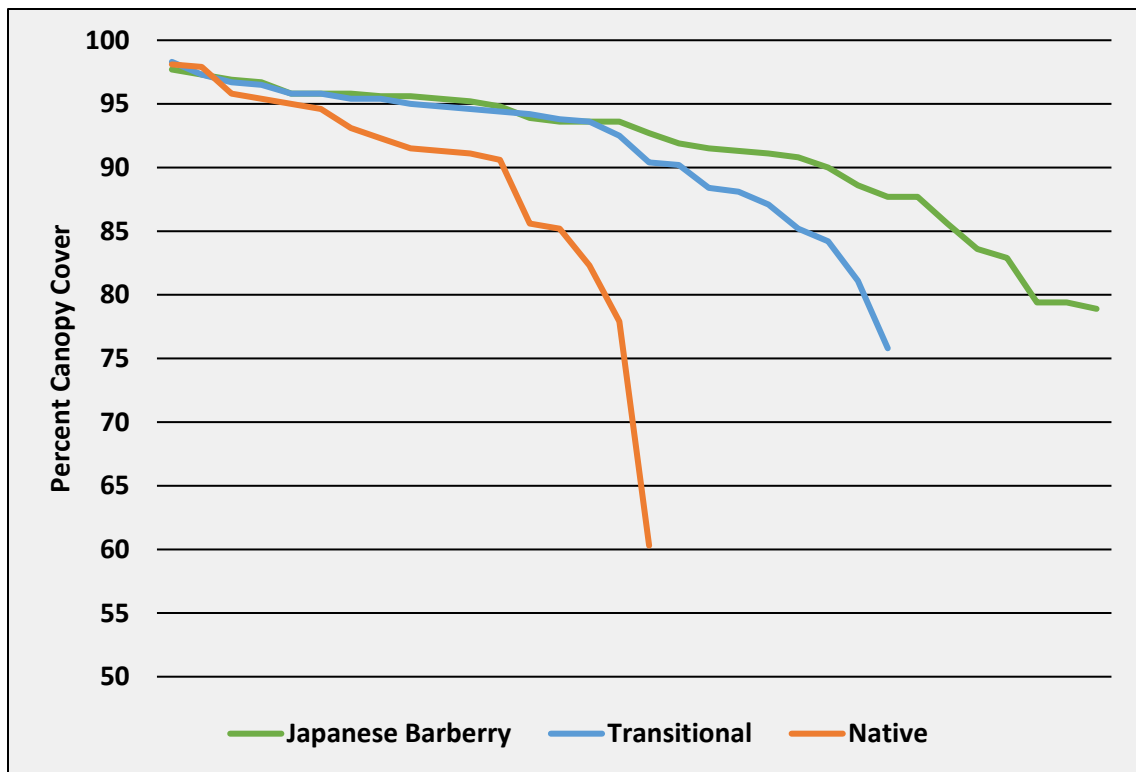


Figure 46. Densiometer readings for all vegetation surveys sorted in descending order for Japanese Barberry-dominated (n = 32), transitional (n = 25), and native understory-dominated (n = 17) plots. Sharp dips in lines indicate the presence of canopy gaps, while longer depressions in lines indicate more frequent canopy openings.

Regression Analysis

Binary logistic regression was performed in order to assess the influence of a number of vegetation parameters on territory occurrence of HOWAs in the study plots. The response (dependent) variable used in this regression was the presence or absence of HOWA territories in vegetation analysis surveys, with available surveys coded as HOWA absent and use surveys coded as HOWA present. The model contained six predictor (independent) variables: mean understory density percentage, mean canopy cover percentage, Japanese Barberry coverage, native shrub coverage, shrub height, and sapling density. The full model containing all predictors was statistically significant,

χ^2 (df = 6, n = 74) = 43.5, $p < 0.001$, indicating that the model was able to distinguish between HOWA presence and absence. The model as a whole explained between 44.4% (Cox and Snell R square) and 60% (Nagelkerke R square) of the variance in HOWA presence/absence, and correctly classified 85.1% of surveys. As shown in Table 13, three of the predictor variables made a unique statistically significant contribution to the model (mean understory density percentage, Japanese Barberry coverage, and shrub height). The strongest predictor of HOWA presence was understory density, recording an odds ratio of 1.086. Japanese Barberry coverage and shrub height were the next strongest predictors of HOWA presence, with odds ratios of 1.045 and 0.199 respectively.

Table 13. Binary Logistic Regression predicting HOWA presence/absence. Bold font indicates statistically significant predictors.

Predictor Variable	B	S.E.	Wald	df	<i>p</i>	Odds Ratio	95% C.I. for Odds Ratio	
							Lower	Upper
Mean Understory Density Percentage	0.082	0.024	12.147	1	<0.001	1.086	1.037	1.137
Mean Canopy Cover Percentage	0.001	0.053	0.000	1	0.982	1.001	0.903	1.110
Japanese Barberry Coverage	0.044	0.018	6.246	1	0.012	1.045	1.010	1.082
Native Shrub Coverage	0.030	0.015	3.776	1	0.052	1.030	1.000	1.061
Shrub Height	-1.615	0.711	5.161	1	0.023	0.199	0.049	0.801
Sapling Density	-0.020	0.036	0.291	1	0.590	0.981	0.913	1.053
Constant	-6.383	5.497	1.349	1	0.246	0.002		

CHAPTER IV

Discussion

Review of Objectives

The primary objective of this study, in the most general sense, was to determine whether Japanese Barberry-dominated understory habitat is superior to native-dominated understory as a HOWA nesting substrate by investigating, quantifying, and explaining the relationship between HOWA and the presence of Japanese Barberry. In order to accomplish this, the primary objective was split into six more specific objectives forming research questions, from which hypotheses were generated. Four of these six questions were answered by the results of this study, and it affirmed that Japanese Barberry-dominated understory is superior as a HOWA breeding habitat in the Delaware Water Gap National Recreation Area.

Objective One: HOWA Territory Occurrence

Kutch (2013), in her 2011-2012 field seasons determined that HOWA detections (primarily the presence of singing males) were relatively high in DEWA in general, and that significantly more individuals were present in areas containing Japanese Barberry-dominated understory than areas dominated by other understory plant species. The current study reaffirms this level of occurrence, and confirms that breeding frequency (defined here as the establishment of breeding territories) does indeed corroborate detection frequency with regard to HOWA preference for Japanese Barberry-dominated habitat (Fig. 28-31).

One concern in the previous study was that HOWA detections may not have accurately reflected breeding frequency since singing males were likely counted multiple times, and singing does not necessarily indicate that a male is breeding. This study resolved this issue, as data was only taken on individuals observed in their territories for the entirety of the breeding season, and most males were banded.

Significantly more HOWA breeding territories occurred in habitat plot types with substantial amounts of Japanese Barberry in the understory than in those with an understory-dominated by native plants (Fig. 31). Therefore, the first null hypothesis, stating that there will be no differences in HOWA territory frequencies between native-dominated and Japanese Barberry-dominated understory habitat types is rejected. HOWA show a significant preference for establishing breeding territories in areas where Japanese Barberry is the dominant or codominant understory species.

Objective Two: Reproductive Success

The null hypothesis that there will be no differences in HOWA reproductive success between native-dominated understory and Japanese Barberry-dominated understory habitats cannot be rejected as too few nests were located in Japanese Barberry-dominated plots and no nests were found in transitional or native understory-dominated plots. The two nests observed in Japanese Barberry during this study, and one nest anecdotally observed outside of the study areas during the same time frame, all failed, and reproductive success was not analyzed due to this small sample size. Although HOWA reproductive success was not determined in this study, adequate data was obtained from other aspects of this study indicative of habitat preference to strongly infer that there is a relationship between HOWA and Japanese Barberry in DEWA.

Difficulties Determining Reproductive Success: Determination of HOWA reproductive success by nest monitoring and comparison of success rates in Japanese Barberry vs. native plants was an important objective of this study. Unfortunately, HOWA nests proved too difficult to locate in DEWA, and meaningful reproductive success data was unattainable. Since this was unexpected, it is worth discussing.

Much of the native sapling-dominated understory that was traditionally found in the northeastern U.S. has now disappeared due to over-browsing by White-tailed Deer. It has been replaced in many areas by a very dense tangled understory comprised of many exotic invasive shrub species, as exemplified by the relative paucity of saplings in

Japanese Barberry-dominated plots. Soil chemistry changes caused by Japanese Barberry may further inhibit sapling growth (Ehrenfeld 1999, Jasch 2009). Although dense shrub thickets in territories were searched for nests in their entirety, the structure of this forest type makes it difficult to visually locate nests built in the understory. After a disappointing 2016 field season with regard to locating nests, advice was sought from Bridget Stutchbury of York University who has worked extensively with breeding HOWA for several decades. In western Pennsylvania and southeastern Canada, HOWA nests are easily found in sapling dominated understory within sporadic, small shrub patches (Stutchbury pers. comm. 2017). In DEWA, most study plots were dominated by extensive expanses of dense shrubs (mostly Japanese Barberry and Spicebush), not sporadic patches, and saplings were sparse. This difference in forest composition is likely the primary reason that nest searching was more difficult in this study than expected from literature accounts. Japanese Barberry was also observed to be deceptively dense during nest searching, which likely makes it a very good nesting substrate as nests in this plant can be easily overlooked.

Howlett and Stutchbury (1996) showed that nest concealment is not important in predator avoidance for HOWA in northwestern Pennsylvania, and that HOWA do not actively conceal nests from which leaf cover is removed. While nest concealment with leaves by HOWA may not be important in DEWA either, the structure of Japanese Barberry is dense enough to make nests not concealed with leaves still difficult to find. Howlett and Stutchbury speculated (1996) that visual concealment is likely unimportant

because most nest predators of HOWA locate nests nocturnally by smell, not visually. If this is true, a dense spiny physical barrier as provided by barberry would be more effective at reducing predation than visual concealment.

In addition to vegetation characteristics, female HOWA are difficult to locate during the nesting season. Before the onset of nesting (mid to late May), females were observed to be very vocal and active. As expected, once nesting began females were seen and heard much less often. Behavioral changes included cessation of most chipping and activity more restricted to skulking through low shrubs instead of foraging higher in the forest. The excellent camouflage of female HOWA (especially young females), coupled with these behavioral changes, contributed to the unexpected difficulty of detecting nests. Unlike many other passerines, male HOWA do not actively defend nests when humans are nearby, and males are rarely observed attending nests before nestlings fledge (Chiver et al. 2011). Since these very conspicuous males give few behavioral clues to nest locations, one must rely on female cues to locate nests, which proved difficult as discussed.

Despite these difficulties, two nests were located during this study, and a third was found incidentally just outside of a study plot. These three nests seemed to be relatively easy to find, all being located near trails, and all reasonably conspicuous from a distance. All of these nests were victims of brood parasitism, predation, or both, perhaps the result of their relative lack of concealment.

Objective Three: Plot Usage by Age

Hooded Warblers in their second or later breeding season (ASY) were significantly more common in plots containing substantial amounts of Japanese Barberry (Japanese Barberry and transitional plots) than in plots with native-dominated understory (Table 1, Fig. 32). This confirms that HOWA utilizing this habitat type are older on average than those individuals utilizing native understory-dominated areas. It has been well documented across Class Aves that older more experienced birds consistently select territories of higher quality than younger birds, and exclude younger birds from these higher quality territories (Hill 1988, Pärt 2001, Ferrer et al. 2003, Reitsma et al. 2008). Therefore, we can be confident that the significantly higher proportion of ASY HOWA occupying Japanese Barberry habitats than native-dominated understory indicates that this habitat type is viewed as superior in quality by those individuals.

It is important to note that the difference in ASY occurrence between plot types was significant while the difference in SY occurrence was not. Young birds have not been demonstrated to consistently choose more beneficial breeding habitats as have older birds, and they are typically excluded from higher quality territories by older birds (Stutchbury 1994). Despite the lack of statistical significance, SY HOWA were proportionally more common in native understory-dominated plots (62.5 percent of all HOWA aged in this plot), than they were in transitional and Japanese Barberry-dominated plots (26.3% of all HOWA aged in these plot types). This seems logical since

SY birds likely choose breeding territories in a more random and less selective fashion than ASY birds and are also likely excluded from Japanese Barberry territories by more dominant older birds.

The null hypothesis for this objective stated that individuals with territories in Japanese Barberry-dominated understory will not be older on average than birds occupying territories in native plant dominated understory, so this null hypothesis is rejected.

Objective Four: Fidelity

Since little data was gathered on reproductive success, site and habitat fidelity could not be correlated to reproductive success. Fidelity was highest in plots containing substantial Japanese Barberry (Japanese Barberry-dominated and transitional plots) with five birds returning to these plots after breeding there in the prior year (Fig. 33). Fidelity was lowest in native plots with just one HOWA returning. However, the sample size of returning birds ($n = 8$) was too low for any meaningful analysis. Intriguingly, two birds that bred in native understory-dominated plots in 2016 bred in transitional plots in 2017. While conclusions can certainly not be drawn from the activities of just two individuals, this does anecdotally support the notion that HOWA learn to prefer Japanese Barberry with age.

Since fidelity could not be correlated with reproductive success and sample size was too small for analysis, I fail to reject the null hypothesis that birds recaptured in the

second field season will choose nesting habitats that show no correlation with their previous reproductive success, and that fidelity will not differ by habitat plot type.

Objective Five: Vegetation Structure and Composition

Vegetation structure and composition in random available habitat areas did differ from HOWA territories (use areas) in several ways. Since Preference/Avoidance values were calculated by subtracting IVs of available vegetation surveys from IVs of use surveys, each of the relatively large preference/avoidance values shown previously indicated differences in shrub or sapling composition between random available habitats and HOWA territories. Significant differences in mean shrub height and understory density percentage between use and available surveys, as well as noticeable differences in foliage height distribution provided further evidence that vegetation structure and composition in territories selected by HOWA is distinctly different than randomly available vegetation.

Regression: In a binary logistic regression performed in order to determine which vegetation components were most responsible for HOWA presence or absence, random available surveys represented the HOWA absent condition of the response variable, while use surveys represented the HOWA present condition. The high significance of the full regression model alone shows that differences existed between use and available surveys. The significant predictor variables of understory density,

Japanese Barberry coverage, and shrub height explained the majority of this variation (Table 13).

Due to each of the factors above, and reaffirmed by the regression, I reject the null hypothesis that vegetation structure and composition will not differ significantly between nesting territories and random available habitat. HOWA territories had significantly more dense understory, showed a preference for Japanese Barberry by HOWA, averaged significantly lower shrub height in Japanese Barberry-dominated plots, and averaged more foliage at low heights than random available habitat.

Objective Six: Suitability of Vegetation to HOWA

Since HOWA prefer to establish nesting territories in areas dominated by Japanese Barberry, one must ask what it is about this plant and habitat type that attracts them. It was hypothesized that the vegetation characteristics found in Japanese Barberry-dominated forest may align well with the known vegetation characteristics preferred by the species: dense understory-dominated by a thick, low, shrub and sapling layer, often near canopy openings created by canopy gaps or forest edges.

While no significant difference in canopy cover density was found between Japanese Barberry-dominated plots and those with more native plants, significant differences were found in shrub height. Canopy openings were more common in Japanese Barberry-dominated plots than transitional or native understory-dominated plots (Fig. 46).

HOWA territory locations were not found to be as commonly associated with canopy gaps in DEWA as literature suggests (Chiver et al. 2011). Presumably, HOWA often occupy territories near canopy openings because these openings allow more sunlight to reach the understory, leading to better developed understory plants with more dense foliage, and more arthropods in the understory for HOWA to forage. Japanese Barberry grows well in full shade and full sun and can form dense thickets regardless of canopy cover conditions (MI DNR 2012). If adequate protective cover for nesting exists away from canopy gaps, these openings may be less important to HOWA in DEWA. Native arthropod density is generally thought to be decreased in Japanese Barberry (with the exception of Black-legged Ticks, which HOWA likely consume), however, adequate food may be provided by the canopy and mid-story.

Use surveys, as expected, had much more dense understory with higher amounts of foliage distribution in the understory layer, but understory density and foliage height distribution across all three plot types was fairly equal (Fig. 43-46). While Japanese Barberry and transitional plots did not show significantly higher understory density than native plots, the significantly lower average shrub height in Japanese Barberry-dominated plots combined with the high understory density align well with known HOWA preferences.

Furthermore, Japanese Barberry's thick, spiny, tangled structure is very comparable to native plants such as *Rubus* spp. and *Ribes* spp. that are known to be traditionally favored by HOWA, but are not nearly as abundant in DEWA as Japanese

Barberry. Although understory density and canopy coverage metrics did not differ significantly between Japanese Barberry and native-dominated understory, shrub height did differ significantly and other noticeable differences existed in parameters favored by HOWA (listed above) that were not statistically analyzed. I am confident in rejecting the null hypothesis that vegetation structure and composition in Japanese Barberry-dominated territories will not better align with known HOWA breeding habitat preferences than native-dominated understory territories.

Nests

The first nest was first found in the Japanese Barberry-dominated plot of study block nine. This nest was approximately one meter high, in the edge of a patch of Japanese Barberry that bordered a trail, and very close to the Delaware River. The female was first observed tending to the nest on 24 May 2016, and it contained one egg. Upon further inspection, this one egg was found to be a BHCO egg (Fig. 47). On May 27, the female appeared to have abandoned the nest, and she was not seen again at this nest. The male and female continued to be observed nearby, and based on their behavior, seemed to have re-nested, but the second nest could not be located. HOWA



Figure 47. Hooded Warbler nest located in the Japanese Barberry-dominated plot of block nine, on 24 May 2017. The egg pictured was laid by a Brown-headed Cowbird (*Molothrus ater*). Photograph by B. Swayser.

have been recorded to abandon nests with BHCO eggs occasionally early in the egg-laying phase (Chiver et al. 2011).

The second nest was found on 18 May 2017. It was approximately 0.75 m high, and again was located in a Japanese Barberry shrub. The patch of barberry containing the nest was large, but the nest was located on the very edge of the patch, about 5 meters from a gravel road, in a utility pole clearing. The female was observed building the nest on May 18, three eggs were laid between May 20 and 23, and a fourth egg was laid shortly thereafter. Incubation began on May 27, and all four eggs hatched on June 5 (Fig. 48). All four nestlings appeared healthy on June 9 and were beginning to grow feathers. On the morning of June 13, the nest was found leaning sideways and empty,



Figure 48. Hooded Warbler nest containing four one-day old nestlings. Taken in the Japanese Barberry-dominated plot of block three on 5 June 2017. Photograph by B. Swayser.

assumed to have been predated the previous night. No signs of nestlings or parents were observed from this point on.

A third HOWA nest was found accidentally by Dr. Greg George on 2 June 2017. The nest was about 100 meters north of the boundary of the native understory-dominated plot of block four. While not officially part of this study due to its location outside of the study block, it was monitored nonetheless due to its close proximity to a study area, and to provide additional HOWA nest data. The placement of this nest was unusual as it was built in a lone grapevine tangle (*Vitis* sp.) suspended from a fallen tree that overhung a trail, about one meter off the ground. The nest location was not in dense understory as is typical for the species, but instead in an open area of native understory-dominated deciduous forest. One large unmarked pale greenish-white egg was observed in the nest with two HOWA eggs on June 2. On June 8, this egg was absent, and three HOWA eggs were present (Fig. 49). The female HOWA appeared to have removed the foreign egg from her nest and replaced it with her own, which has not previously been recorded in HOWA (Chiver et al. 2011). While BCHO eggs are typically heavily marked with brown speckling, and not drastically larger than HOWA eggs, this egg was unmarked and much larger than the HOWA eggs. The only other brood parasitic species in this region are Black and Yellow-billed Cuckoos (*Coccyzus erythrophthalmus* and *Coccyzus americanus*, respectively), which both are facultative brood parasites that rarely perform interspecific brood parasitism and typically lay eggs in nests higher in the forest canopy (Hughes 1999). This egg most closely resembled

those of Yellow-billed Cuckoos, and appears to have been laid by this species (Baicich and Harrison 2005, Hauber 2014). While HOWA do not typically replace BHCO eggs laid in their nests, this egg may have looked different enough to the female from her own eggs for her to recognize it as foreign and remove it.



Figure 49. Nest found outside of native plot of block 4. Left: picture taken on 2 June 2017 by Greg George showing two HOWA eggs and one foreign egg. Right: picture taken on June 8 by Brandon Swayser showing three HOWA eggs in the same nest.

Hooded Warbler- Japanese Barberry Relationship

HOWA Preference for Japanese Barberry

The results of this and Kutch's study indicate that HOWA preferentially select breeding territories in understory dominated by Japanese Barberry. However, the reasons for this preferential selection of Japanese Barberry are less readily apparent.

The most logical conclusion is that the dense spiny structure of Japanese Barberry provides protection for HOWA which are known to prefer a dense and often spiny or thorny understory for nesting. The structure of this plant likely deters nest predators and brood parasites, protects fledglings from ground predators, and perhaps deters incidental nest damage by large herbaceous browsers such as White-tailed Deer. Since deer do not typically enter barberry thickets to browse during the summer, incidental damage by browsing as well as predation of nestlings by deer may be avoided by nesting in Japanese Barberry.

Japanese Barberry-dominated plots did not have higher understory density readings than transitional or native understory-dominated plot types during vegetation analysis. The method used to determine understory density measured visual concealment of a gridded vertical board by understory foliage. This may not be the best way to assess the true density of Japanese Barberry as the shrub is lower than most other shrubs measured, three-dimensionally dense, and studded with spines. The dense native understory plants measured that constitute more traditional HOWA nesting substrate, such as Spicebush, American Beech Saplings, and Northern Dewberry, fill more vertical space than Japanese Barberry, but grow in a much simpler vertical profile, lacking the sprawling, tangled three-dimensional growth of Japanese Barberry. No ideal metric could be found to measure the three-dimensional density or spine coverage of this plant, but these factors are most likely what makes this plant more protective and preferable to HOWA than its native analogs.

A second possible reason for the preference of Japanese Barberry by HOWA is that there may be less competition for this habitat which may be relatively unoccupied by several shrub nesting species that avoid this plant and would otherwise act as competitors to HOWA. Gray Catbirds were found to avoid nesting in Japanese Barberry in one study (Nickell 1965), although some research has suggested that the opposite is true (Speicher et al. unpublished data). Kutch found Gray Catbirds and Ovenbirds (shrub and ground-nesters respectively) to occupy Japanese Barberry-dominated and transitional plots less often than native understory-dominated plots (2013).

In past studies of passerines utilizing exotic invasive shrubs, it has been postulated that these plants act as an ecological trap to the birds. Since they are rather abundant and dense, researchers fear that these plants may be utilized merely because of their abundance and apparent density, despite having a negative effect on reproductive success. Meyer et al. (2015) found this not to be the case with Veery, and it does not seem to be true for HOWA either. HOWA have been known to occupy Japanese Barberry-dominated areas in DEWA since around 2010, and populations have increased rather than decreased during this time, which would not be the case if this relationship represented an ecological trap. Not only is Japanese Barberry widely available, but it also best fits HOWA's breeding habitat preferences (dense and often thorny or spiny shrubs), and likely does not represent a trap.

HOWA Territory Size

Mean HOWA territory area in this study was found to be larger in Japanese Barberry-dominated plots than in transitional or native understory-dominated plots. It has been demonstrated that Japanese Barberry outcompetes native lepidopteran host plants and that lepidopteran larval density is decreased in areas invaded by this plant (Burghardt et al. 2010). Given that lepidopteran larvae are an important food source for HOWA, and that this pattern may also be seen with other arthropods, larger territories in plots devoid of most native shrubs and saplings may reflect the need to establish larger territories to compensate for reduced food availability in Japanese Barberry-dominated plots.

HOWA in DEWA

Hooded Warblers were thought of as uncommon in DEWA as recently as the early 2000's, but are now locally abundant within the National Recreation Area. Citizen science data from Cornell Lab of Ornithology's eBird® project reflects this relatively recent increase in abundance. While eBird does not provide an accurate measure of population growth, it does help to improve the general understanding of avian distribution patterns and the environmental and anthropogenic factors that influence them (Sullivan et al. 2009). In an area such as DEWA that historically has been heavily birded, eBird data reflects general species population trends, and the increase of HOWA in this area is notable. This citizen science database was developed in 2002, and has

seen a dramatic increase in users in the past decade (eBird 2017). The following maps show eBird data for HOWA occurrence in DEWA from 2012 and 2017 (Fig 50). Earlier years are not shown for comparison as eBird was not as widely used, and earlier data would be skewed by fewer users. However, comparing the density of HOWA sightings on these maps to PA Breeding Bird Atlas data collected from 2004-2009 (Fig. 11) shows the increase of this species in DEWA since the early 2000s.

There are many plausible reasons for the increase of the HOWA population in DEWA, and ultimately it is probably due to multiple factors. Two factors that have possibly played important roles are the invasion of Japanese Barberry and the effects of climate change. The increases of both Japanese Barberry and HOWA in this area have been dramatic and well aligned from 2000 to present (Fig. 16). The increased presence of this plant and HOWA's affinity for it may be contributing to their increase in DEWA, but causation cannot be implied without further research into this association.

Climate change may also be causing HOWA range to shift north into this region, as the core of HOWA range was formerly further south than it is now (Fig. 9). While climate change may explain the general increase of HOWA in the northeastern U.S., it would not explain the relative abundance of HOWA in DEWA compared to neighboring regions (Fig. 50). Food and/or habitat resources present in DEWA better explain its exceptional abundance of many Parulids relative to the surrounding area.

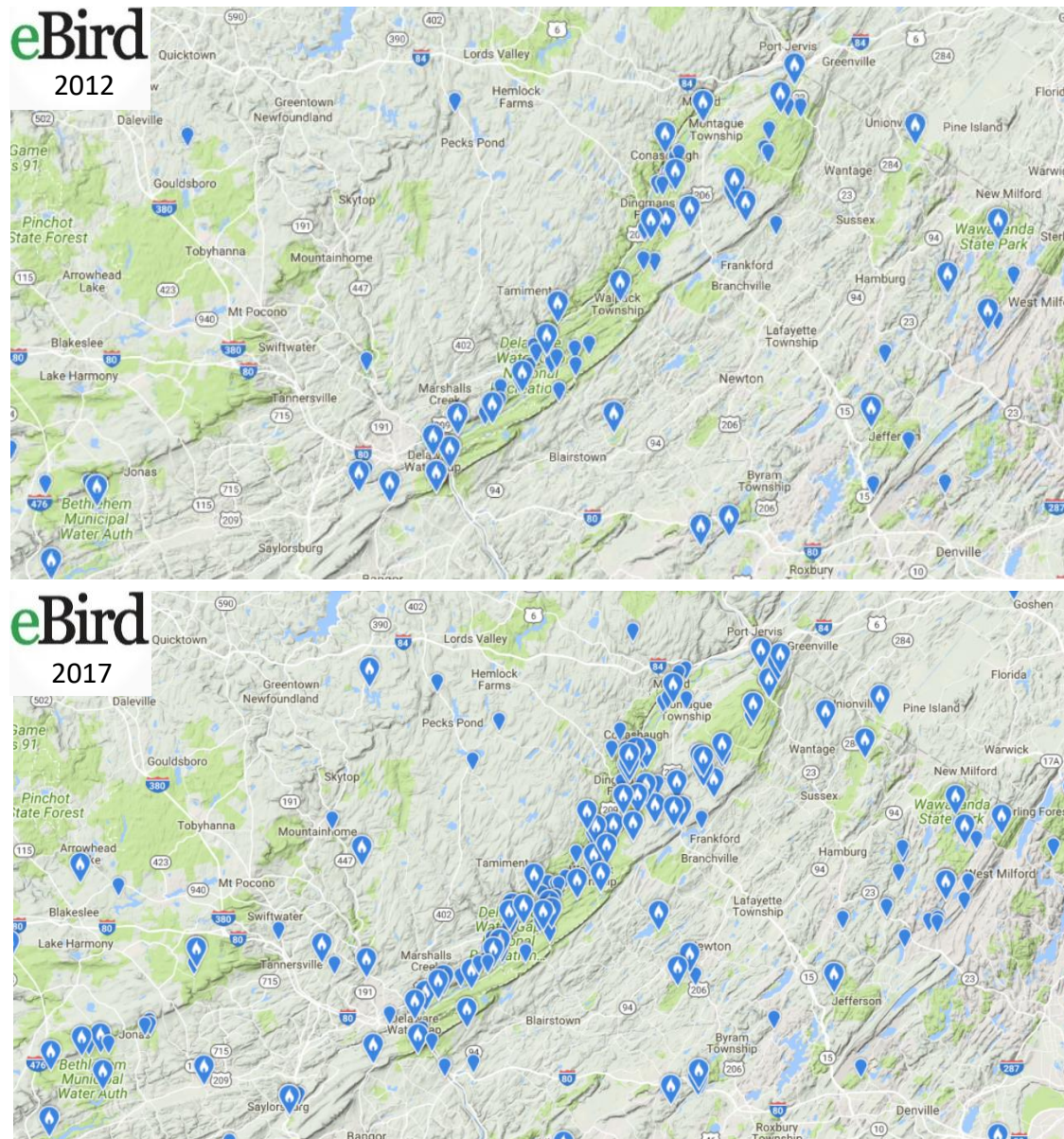


Figure 50. HOWA occurrence maps of DEWA and vicinity from eBird data. Blue pins represent sightings of one or more HOWA. Top: 2012. Bottom: 2017 (eBird 2017).

Japanese Barberry in DEWA

Japanese Barberry is thought to have been first introduced into DEWA in the late 1960's (Hillaire pers. comm.), and the National Park Service currently recognizes it as a

problematic non-native invasive species (NPS 2016b). It has been known to be widespread in the park since 1997 at the latest (Ehrenfeld 1997). In a twenty year old study of Japanese Barberry's invasion of the New York City Metropolitan region, Ehrenfeld placed Japanese Barberry populations into four categories including "extended populations," which indicated long diffuse stretches of Japanese Barberry along roadsides, "sparse plants" areas, "many plants" areas, and "dense thickets" (1997). As of 1997, two extended populations areas, one sparse plants area, four many plants areas, and one dense thicket were found in the entirety of DEWA, and Ehrenfeld also noted that most trails she traversed had at least one small plant (1997). As of 2017, I can confidently say through personal observation that nearly every road in DEWA contains large stretches of what Ehrenfeld defined as "extended populations", and that the southern half of DEWA alone contains greater than 20 dense thickets occupying greater than five ha each.

Japanese Barberry is currently one of the most dominant shrub species in DEWA, and its dominance is increasing. Two pieces of anecdotal evidence for this trend were observed. When scouting plots for this study in early spring of 2016, Kutch's plots were used as a starting point (Kutch 2013). Two study blocks used by Kutch had to be relocated, and several native-dominated understory plots had to be adjusted or relocated because they no longer contained substantial native plants, having been invaded by Japanese Barberry and other exotic shrubs in less than four years. Additionally, between the two field seasons of this project, native-dominated plot areas

that contained little to no Japanese Barberry in 2016 were found to contain noticeably more of the plant in 2017.

The monoculture of Japanese Barberry in Japanese Barberry-dominated study plots was well supported by vegetation analysis results (Table 9). Plots referred to as “ecotone” in Kutch’s study were renamed “transitional” in this study as it became clearer that areas co-dominated by Japanese Barberry and native plants are likely to become Japanese Barberry thickets over time (Table 10). As noted in vegetation analysis results, native-dominated plots were mostly co-dominated by Spicebush and Blueberry (*Vaccinium* spp.), but still featured Japanese Barberry (mostly very small plants) as their third most ecologically important plant, with a relative density of approximately 17% (Table 11).

Given this quantitative and anecdotal evidence, it is clear that Japanese Barberry has become a permanent invader in DEWA. Much of the forest understory in the recreation area will most likely become a Japanese Barberry monoculture in the near future, which has negative implications for the area’s wildlife with the probable exception of HOWA and possibly other shrub-nesting passerines.

Vegetation Analysis- Additional Trends

During vegetation analysis, several interesting trends were noticed in vegetation parameters that did not necessarily pertain to HOWA. Rather than being listed in the

results section with trends that were more relevant to HOWA, they are briefly discussed here.

Species Composition

During vegetation analysis, several distinct trends were noticed in tree and sapling species composition across plot types and use vs. available surveys. As mentioned previously, Sugar Maple had a far higher IV than any other tree species in Japanese Barberry-dominated plots (Table 3) and was the only tree species present in many surveys of this plot type. Sugar Maple was also the most common tree in transitional plots, where it was codominant with Black Birch, but less so than in Japanese Barberry-dominated plots (Table 4). In native understory-dominated plots, Sugar Maple was far less common, and was the third most important tree after Eastern Hemlock and Black Birch (Table 5). A similar pattern was seen with saplings as Sugar Maple was the second most ecologically important sapling species in Japanese Barberry-dominated plots after Black Walnut (*Juglans nigra*) and was much less ecologically important in the other two plot types. Sugar Maple is known to be dominant in late successional forests, and Japanese Barberry probably became established after large, mature trees already dominated these forest areas. However, these plots also contained more young Sugar Maple trees and saplings (likely younger than the Japanese Barberry) than young trees and saplings of other species, showing that either Sugar

Maple is more tolerant of soil conditions created by Japanese Barberry than other plants, or that its dominance in DEWA is completely unaffected by this invasive shrub.

Japanese Barberry may prefer habitats occupied by sugar maple and the conditions that this species creates, but no literature on this topic exists. Regardless, there appears to be a strong association between Japanese Barberry thickets and Sugar Maple, and this association may justify further study.

Canopy Height

Measures of canopy height were not statistically analyzed or included in the results section since HOWA breeding is more directly dependent on understory conditions than canopy conditions, but it was noted that average canopy height in native understory-dominated plots was lower than those with substantial amounts of Japanese Barberry. Mean canopy height was 28.1 m in Japanese Barberry-dominated plots, 27.2 m in transitional plots, and 24 m in native understory-dominated plots. This trend was also seen in foliage height distribution surveys (Fig. 42-44). Native understory-dominated plots were dominated by large tree species, meaning that native plots must have been younger on average for canopy height to differ in this manner (Table 5). Japanese Barberry is a generalist that has not been shown to prefer older forests (PA DCNRa), so the reason for this pattern is unknown, however, its presence in forests dominated by a late successional species (Sugar Maple) may suggest that it prefers older forest patches in DEWA.

HOWA Sapling Avoidance Data

The most notable trend seen in the preference/avoidance values calculated for saplings was the avoidance of Eastern Hemlock by HOWA. A relatively large avoidance value was calculated for saplings of this species in native understory-dominated plots (Fig. 38), and although not included in the results, an even stronger avoidance value (-12.07) was calculated for mature Eastern Hemlock trees. HOWA are known to nest in mixed deciduous/coniferous forests similar to where many of these hemlocks were measured in available surveys (Chiver et al. 2011). However, Eastern Hemlock foliage in DEWA has been severely degraded by the invasive Hemlock Woolly Adelgid (*Adelges tsugae*) (Napoli 2015), and the lack of cover given by these deteriorated trees, especially in the most impacted low branches that extend into the understory, may explain its avoidance by an understory nesting bird species such as HOWA.

HOWA Shrub Preference Data

One of the most intriguing results from vegetation analysis was the shrub preference/avoidance values calculated from shrub IVs in use and available surveys. Previous studies on HOWA nesting in exotic invasive species have examined a suite of exotic invasive species including Japanese Barberry, rather than investigating this barberry species alone (Schlossberg and King 2010, Garrett 2015). Vegetation surveys showed several other exotic invasive shrubs in the study plots, but HOWA territories showed a strong preference for Japanese Barberry and an avoidance for other common

shrubs such as Autumn Olive, Multiflora Rose, and Burning Bush (*Euonymus alatus*) (Fig. 39). These results added further evidence for the preference of Japanese Barberry by HOWA.

Japanese Barberry Management: a Paradox

Many species of wildlife, including passerine birds, are declining across their North American range, and habitat destruction and degradation caused by the invasion of non-native plants makes a major contribution to these declines (Pimentel et al. 2005, Sauer et al. 2017). The negative effect that Japanese Barberry's invasion has on wildlife has been thoroughly documented, however, HOWA populations are stable or increasing in most areas including DEWA (Sauer et al. 2017). Japanese Barberry will continue to spread throughout much of the HOWA's range, and as this occurs the species will have increased opportunity to breed in this underutilized habitat type where territory density appears to be high. The same is likely true for several other shrub-nesting bird species that have been observed nesting in or near this plant, such as the Eastern Towhee and Chestnut-sided Warbler.

The invasion of Japanese Barberry therefore creates a paradox. Over-browsing of native forest understory by White-tailed Deer will continue to create open niches in the northeastern U.S. as long as high deer populations remain uncontrolled. Japanese Barberry will continue to dominate these open niches. One must weigh the negative impacts of Japanese Barberry's invasion against the possibly more negative alternatives.

If this shrub hypothetically did not invade or was well controlled by management, native plants would still struggle to survive over-browsing and the result would be either an absence of understory altogether, or dominance by other exotic invasive plant species. Both of these alternatives would undoubtedly be worse for HOWA and other shrub nesting passerines than the Japanese Barberry thickets that they successfully nest in currently.

While HOWA and Japanese Barberry have increased in DEWA simultaneously, it must be noted that this could be merely a coincidental correlation and does not necessarily indicate that the increase of Japanese Barberry is causing the increase of HOWA. However, given the demonstrated relationship between the two species and the preference of Japanese Barberry by HOWA (especially ASY birds), it is possible that the plant benefits HOWA, and reproductive success data, if ever obtained in Japanese Barberry substrate, could solidify this.

Attempts have been made to restore native plants to Japanese Barberry thickets by removing all barberry shrubs, excluding deer, and planting native species. It has been found that native plants grow too slowly, and are hindered by the irreversible changes in soil chemistry caused by Japanese Barberry; specifically higher pH and changes in nitrogen compound composition (Ehrenfeld 1999, Jasch 2009). Ultimately, Japanese Barberry regenerates and dominates again despite attempted restoration efforts.

Japanese Barberry is an invasive shrub species that will probably never be eradicated despite its negative impacts on wildlife. Population control of White-tailed

Deer is vitally important to conserving biodiversity in this region and habitat managers actively work to solve this issue, but even if deer were to be controlled, the invasion of Japanese Barberry might still persist. The control of Japanese Barberry in DEWA is strongly encouraged in order to conserve the remaining biodiversity of the recreation area, which is relatively high compared to nearby areas. As the distribution of native shrubs continues to decline, interspecific and intraspecific competition will increase among animal species that are unable to inhabit Japanese Barberry monoculture, likely resulting a decline in their populations within DEWA.

Faced with the relative benefit that this plant may provide to Hooded Warblers and possibly other shrub nesting species, habitat managers will weigh the negative consequences of Japanese Barberry's invasion and its degradation of the area's ecosystems against the futility of attempting to eradicate it.

Future Directions

Several areas of this project would benefit from further study. The comparison of reproductive success data between Japanese Barberry and native substrate would help to further explain the relationship between HOWA and this exotic invasive plant, and may show that HOWA success has benefitted from this invasion. Fledgling density and fledgling success have been demonstrated to be useful in determining HOWA reproductive success (Stutchbury et al. 1994), and collecting this data may be easier

than locating nests in dense understory. However, nest success should be further investigated, and more reliable methods of locating nests in DEWA should be pursued.

Additional GPS coordinates of HOWA territory boundaries could be collected over longer periods of time to ensure that territory size is portrayed as accurately as possible (Barg et al. 2005). If larger quantities of coordinates are obtained in each territory, the kernel density tool of ArcMap® could be used, which would provide more accurate area estimates than the point aggregate tool. Additionally, if HOWA are followed for longer periods of time, they are more likely to be seen signing over larger portions of their territories.

HOWA are known to eat a variety of arthropods (Chiver et al. 2011) and likely consume Black-legged Ticks, which are abundant in Japanese Barberry thickets. HOWA fecal analysis could determine whether this tick species plays an important role in HOWA diets. Consumption of Black-legged ticks, if significant could be an important finding in the fields of ecology and public health.

Additional HOWA site and habitat fidelity data should be sought, as a larger sample size of returning birds may show differences in fidelity between Japanese Barberry and native understory habitat types. If more banding is conducted, and searching for returning HOWA is less geographically restricted (as it was by plot boundaries in this study), fidelity data should be more attainable. Fidelity of individuals could also be compared to their reproductive success, if success can be measured.

Finally, the correlation and possible relationship between Japanese Barberry thickets and Sugar Maple should be further investigated.

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Appendix I. East Stroudsburg University IACUC Approval Page for banding HOWA.

Signatures

I certify that the above information is accurate and complete, that I have read and agree to abide by East Stroudsburg University's *Policy on Animal Care and Use*, that I will make copies of these policies and other pertinent guidelines available to those persons who work under my supervision, and that deviations from this protocol, including any unanticipated injuries or death of animals, will be reported to the IACUC. Further, my level of supervision will be such that these procedures will be carried out in a humane and a scientifically acceptable manner as described herein. I understand that, as the research supervisor, I take responsibility for the conduct of anyone working under this approved protocol, and I will supervise the research to ensure that no work is conducted that is not covered herein or in a separate approved protocol. I am aware that my research might require permits from federal and/or state agencies that regulate the capture, transport, maintenance, handling, and manipulation of live vertebrate animals, and I certify that my research will be conducted in accordance with all relevant federal and state laws. I also certify that proposed experiments do not unnecessarily duplicate the research of other investigators.

Signature, Principal Investigator

Date

Appendix I Continued. East Stroudsburg University IACUC Approval Page.

FOR IACUC USE ONLY

☐ Procedures are exempt from full IACUC review because they are purely observational, non-invasive, and produce no perceptible discomfort or they concern only the use of tissues from dead animals. To be considered exempt, tissues from dead animals must be obtained from animals euthanatized or otherwise killed by means, and for purposes, unrelated to the proposed project. The protocol must be approved by the Chair and two additional members of the IACUC.			
☐ Procedures will be minimally invasive or produce relatively little discomfort. Protocols may involve bleeding, injections, minimal sampling, anesthesia, or humane euthanasia without prior invasive manipulation. Protocols must be reviewed by the IACUC. The protocol must be approved by the Chair and two additional members of the IACUC.			
☐ Procedures will be invasive or involve prolonged manipulation. Protocols may involve surgical or other stimuli inducing pain or distress, but all pain or distress will be mitigated with appropriate anesthetics or analgesics. Protocols must be reviewed by the IACUC. The protocol must be approved by the Chair, the Veterinarian, and one additional member of the IACUC.			
☐ Procedures will be invasive and may cause prolonged physiological or psychological stress. Pain, considerable distress, or discomfort will be induced and not mitigated by anesthesia or adequate analgesia. Protocols must be reviewed by the IACUC. The protocol must be approved by the Chair, the Veterinarian, and two additional members of the IACUC.			
_____ Signature, IACUC Chair	_____ Date	☐ Approve	☐ Disapprove
_____ Signature, IACUC Member	_____ Date	☐ Approve	☐ Disapprove
_____ Signature, IACUC Member	_____ Date	☐ Approve	☐ Disapprove
_____ Signature, IACUC Member	_____ Date	☐ Approve	☐ Disapprove
_____ Signature, IACUC Member	_____ Date	☐ Approve	☐ Disapprove
_____ Signature, IACUC Veterinarian	_____ Date	☐ Approve	☐ Disapprove

Appendix II. Bird Banding Permit Numbers.

**United States Department of the Interior, United States Geological Survey Federal Bird
Banding Permit**

Permit Number: 23729

New Jersey Division of Fish and Wildlife Scientific Collecting Permit

Permit Number: SC 2017098

Pennsylvania Game Commission Bird Banding Special Permit

Permit Number: 21018

**United States Department of the Interior, National Park Service Scientific Research
and Collecting Permit**

Permit Number: DEWA-2017-SCI-0010

Appendix III. Study Block Numbers and Habitat Plot GPS Coordinates.

Block No.	Japanese Barberry	Native	Transitional
1	N 41.09373	N 41.09400	N 41.09402
	W 74.95587	W 74.96006	W 74.95808
2	N 41.08215	N 41.07981	N 41.08095
	W 74.96100	W 74.96574	W 74.96204
3	N 41.07421	N 41.07291	N 41.07751
	W 74.96207	W 74.96774	W 74.96115
4	N 41.08229	N 41.08684	N 41.08513
	W 74.98820	W 74.97995	W 74.98279
5	N 41.07430	N 41.07596	N 41.07503
	W 75.01671	W 75.01483	W 75.01582
6	N 41.06465	N 41.06886	N 41.06772
	W 75.01489	W 75.01350	W 75.01307
7	N 41.04297	N 41.04075	N 41.04176
	W 75.01762	W 75.02119	W 75.01948
8	N 41.02428	N 41.02883	N 41.03039
	W 75.05382	W 75.04292	W 75.03900
9	N 40.9883	N 40.98942	N 40.98583
	W 75.12874	W 75.12646	W 75.13002
10	N 40.97940	N 40.97844	N 40.97619
	W 75.14278	W 75.14140	W 75.13949

Appendix IV. HOWA Territory GPS Coordinates- 2016.

Plot Type Legend: Japanese Barberry-dominated Plot indicated by “J”, Transitional Plot indicated by “T”, and Native Understory-dominated Plot indicated by “N”.

Random Territory Number	Block Number	Plot Type	GPS Coordinates	
			Latitude (N)	Longitude (W)
57	1	J	41.09481	74.94688
30	1	T	41.0941	74.95839
39	1	T	41.09451	74.95837
41	2	T	41.08123	74.96201
26	2	T	41.08002	74.96300
21	2	T	41.08023	74.96419
20	3	J	41.07407	74.96175
1	3	J	41.07352	74.96375
3	3	J	41.07537	74.96085
60	3	J	41.07455	74.96255
61	3	N	41.07207	74.96995
63	3	N	41.07304	74.96965
93	4	N	41.08500	74.97879
86	4	T	41.0862	74.9806
84	4	T	41.08362	74.9854
95	4	T	41.08472	74.98338
32	5	J	41.07438	75.0172
8	6	J	41.06409	75.01529
49	6	N	41.06903	75.01343
4	6	N	41.06903	75.01343
40	6	T	41.0673	75.0139
29	7	J	41.04305	75.01759
22	7	T	41.04222	75.01842
50	8	J	41.02483	75.05287
17	9	J	40.98988	75.12923
77	9	T	40.98623	75.12962
51	10	N	40.97793	75.14321

Appendix IV Continued. HOWA Territory GPS Coordinates- 2017.

Plot Type Legend: Japanese Barberry-dominated Plot indicated by “J”, Transitional Plot indicated by “T”, and Native Understory-dominated Plot indicated by “N”.

Random Territory Number	Block Number	Plot Type	GPS Coordinates	
			Latitude (N)	Longitude (W)
43	1	J	41.09518	-74.94763
69	1	T	41.09404	-74.95773
91	2	J	41.08216	-74.96128
41	2	T	41.08062	-74.96292
14	3	T	41.07716	-74.96124
11	3	N	41.07205	-74.96146
98	3	J	41.07408	-74.96429
12	3	J	41.07408	-74.96429
52	3	J	41.07241	-74.9614
62	4	J	41.08163	-74.98923
93	4	T	41.08581	-74.98181
95	4	T	41.08522	-74.98237
87	5	J	41.07373	-75.06153
47	6	J	41.06377	-75.01609
81	6	J	41.06377	-75.01609
4	6	T	41.06744	-75.01348
99	7	T	41.04161	-75.01984
2	8	J	41.02508	-75.05254
77	9	T	40.98576	-75.13015
10	9	J	40.99010	-75.12891
17	9	J	40.98972	-75.12824
51	10	N	40.97764	-75.14307

Appendix V. Banding Data for 2016 and 2017 Field Seasons.

Band No.	2820-02701	2820-02702	2820-02703	2820-02704	2820-02705	2820-02706
Color Bands: right leg, left leg	Red/white, red over red	Red/white, l. blue over l. blue	Red/white, l. blue over red	Red/white, l. blue over orange	Red/white, orange over orange	Red/white, d. blue over d. blue
Territory No.	41	20	40	49	4	8
Date Banded	5/9/2016	5/9/2016	5/10/2016	5/10/2016	5/10/2016	5/11/2016
Bird Mass (g)	11	9.6	11	11	10.5	11
Fat Score (0-6)	0	0	0	0	0	0
Wing Chord (mm)	65	69	67.5	67	67.25	67
Tail Length (mm)	56	58.5	56.5	56.5	55	56.5
Age	SY	SY	ASY	SY	ASY	ASY
Sex	M	M	M	M	M	M

Band No.	2820-02707	2820-02708	2820-02709	2820-02710	2820-02711	2820-02712
Color Bands: right leg, left leg	Red/white, d. blue over red	Black, white over red	Black, d. blue over white	Black, d. blue over orange	Black, white over l. blue	Black, d. blue over red/yellow
Territory No.	86	84	95	95	51	32
Date Banded	5/11/2016	5/11/2016	5/11/2016	5/11/2016	5/13/2016	5/15/2016
Bird Mass (g)	10.5	11.5	11	10.5	11	10.5
Fat Score (0-6)	0	0	0	0	0	0
Wing Chord (mm)	67	67	66	63	65.5	67
Tail Length (mm)	55	56	55	54	54	56
Age	ASY	ASY	ASY	AHY	SY	ASY
Sex	M	M	M	F	M	M

Appendix V Continued.

Band No.	2820-02713	2820-02714	2820-02715	2820-02716	2820-02717	2820-02718
Color Bands: right leg, left leg	Black, white over white	Black, black/white over orange	Black, red/blue over l. blue	Black, l. blue over d. blue	Black, orange over black	Black, orange over red/blue
Territory No.	93	77	17	50	22	29
Date Banded	5/17/2016	5/31/2016	5/31/2016	5/31/2016	6/1/2016	6/1/2016
Bird Mass (g)	10.8	11	11	11	11	11.5
Fat Score (0-6)	0	0	0	0	0	0
Wing Chord (mm)	67.5	65	66.5	68	64	66
Tail Length (mm)	56	55	56.5	57.5	54.5	54
Age	SY	SY	ASY	ASY	ASY	ASY
Sex	M	M	M	M	M	M

Band No.	2820-02719	2820-02720	2820-02721	2820-02722	2820-02723	2820-02724
Color Bands: right leg, left leg	Black, black/white over d. blue	Black, white over orange	Black, white over black/white	Black, black/white over black/white	Black, d. blue over black	Black, black over black
Territory No.	61	26	1	63	3	60
Date Banded	6/1/2016	6/3/2016	6/4/2016	6/6/2016	6/6/2016	6/7/2016
Bird Mass (g)	10.5	11.5	11	10.5	11	11
Fat Score (0-6)	0	0	0	0	0	0
Wing Chord (mm)	66.5	70	68	68.5	70	67
Tail Length (mm)	57	57	56	57.5	58	56
Age	SY	ASY	SY	ASY	ASY	SY
Sex	M	M	M	M	M	M

Appendix V Continued.

Band No.	2820-02725	2820-02726	2820-02727	2820-02728	2820-02729	2820-02730
Color Bands: right leg, left leg	Black, black/white over red/blue	Black, black over white	Black, red/blue over white	Black, red/blue over red/blue	Red, light blue over blue	Red, blue over blue
Territory No.	21	30	39	57	33	2
Date Banded	6/7/2016	6/7/2016	6/10/2016	6/10/2016	5/8/2017	5/8/2017
Bird Mass (g)	10.5	10.5	11	10.5	9	11.5
Fat Score (0-6)	0	0	0	0	0	0
Wing Chord (mm)	68	67	68	68.5	66	68.5
Tail Length (mm)	57	57	60	57	55.5	58
Age	ASY	ASY	ASY	SY	ASY	ASY
Sex	M	M	M	M	M	M

Band No.	2820-02731	2820-02732	2820-02733	2820-02734	2820-02735	2820-02736
Color Bands: right leg, left leg	Red, blue over red/blue	Red, light blue over orange	Red, orange over blue	Red, black over yellow	Red, blue over red	Red, orange over orange
Territory No.	4	69	11	47	14	52
Date Banded	5/11/2017	5/17/2017	5/20/2017	5/22/2017	5/23/2017	5/30/2017
Bird Mass (g)	12	10.5	11	11	11	12
Fat Score (0-6)	0	0	0	0	0	0
Wing Chord (mm)	62	65.5	71	68.5	68	65
Tail Length (mm)	51	53.5	56	57	56	52
Age	ASY	SY	ASY	SY	SY	ASY
Sex	F	M	M	M	M	F

Appendix V Continued.

Band No.	2820-02737	2820-02738	2820-02739	2820-02740	2820-02741
Color Bands: right leg, left leg	Red, black/white over red/blue	Red, l. blue over white	Red ,l. blue over l. blue	Red, black over white	Red, red/blue over orange
Territory No.	52	81	62	62	87
Date Banded	5/30/2017	6/1/2017	6/8/2017	6/8/2017	6/15/2017
Bird Mass (g)	11	11.25	11	11	11.5
Fat Score (0-6)	0	0	0	0	0
Wing Chord (mm)	66.5	70.5	63	69	70
Tail Length (mm)	52	58	51	54	58
Age	AHY	ASY	ASY	SY	ASY
Sex	M	M	F	M	M

Appendix VI. GPS Coordinates of Nest locations.

Block No.	Plot Type	GPS Coordinates	Substrate Species	Territory No.
9	Barberry-dominated	N 40.99043 W 75.12936	<i>Berberis thunbergii</i>	17
3	Barberry-dominated	N 41.07406 W 74.96163	<i>Berberis thunbergii</i>	52
Outside of Block 4	Outside of Native Plot	N 41.09024 W 74.97680	<i>Vitis</i> sp.	none

Appendix VII. Complete Tree Ecological Importance Values by Plot Type.

Japanese Barberry-dominated Plots.

Common Name	Species Name	IV	IV%
Sugar Maple	<i>Acer saccharum</i>	1.28	42.56
Green Ash	<i>Fraxinus pennsylvanica</i>	0.19	6.48
White Ash	<i>Fraxinus Americana</i>	0.18	6.14
Black Walnut	<i>Juglans nigra</i>	0.16	5.40
Eastern Hemlock	<i>Tsuga Canadensis</i>	0.16	5.21
Black Birch	<i>Betula lenta</i>	0.12	3.95
Northern Red Oak	<i>Quercus rubra</i>	0.11	3.55
Black Locust	<i>Robinia pseudoacacia</i>	0.10	3.48
Red Maple	<i>Acer rubrum</i>	0.08	2.79
Slippery Elm	<i>Ulmus rubra</i>	0.08	2.64
American Hornbeam	<i>Carpinus caroliniana</i>	0.07	2.26
White Pine	<i>Pinus strobus</i>	0.05	1.83
Pignut Hickory	<i>Betula lenta</i>	0.04	1.41
Chestnut Oak	<i>Quercus montana</i>	0.04	1.41
Tulip Poplar	<i>Liriodendron tulipifera</i>	0.04	1.40
Eastern Red Cedar	<i>Juniperus virginiana</i>	0.04	1.33
Mockernut Hickory	<i>Carya tomentosa</i>	0.04	1.21
Shagbark Hickory	<i>Carya ovata</i>	0.03	1.05
Black Tupelo	<i>Nyssa sylvatica</i>	0.03	1.01
Black Oak	<i>Quercus velutina</i>	0.03	0.93
Black Cherry	<i>Prunus serotina</i>	0.03	0.91
Common Serviceberry	<i>Amelanchier arborea</i>	0.03	0.84
Sycamore	<i>Platanus occidentalis</i>	0.02	0.55
Flowering Dogwood	<i>Cornus florida</i>	0.02	0.53
Tamarack	<i>Larix laricina</i>	0.01	0.50
Sassafras	<i>Sassafras albidum</i>	0.01	0.45
Hophornbeam	<i>Ostrya virginiana</i>	0.01	0.44
Chinquapin Oak	<i>Quercus muehlenbergii</i>	0.01	0.43

Appendix VII Continued.

Transitional Plots.

Common Name	Species Name	IV	IV%
Sugar Maple	<i>Acer saccharum</i>	0.61	20.18
Black Birch	<i>Betula lenta</i>	0.51	17.08
Northern Red Oak	<i>Quercus rubra</i>	0.37	12.37
Red Maple	<i>Acer rubrum</i>	0.25	8.17
White Oak	<i>Quercus alba</i>	0.16	5.18
Black Cherry	<i>Prunus serotina</i>	0.15	4.99
Green Ash	<i>Fraxinus pennsylvanica</i>	0.10	3.36
Eastern Hemlock	<i>Tsuga Canadensis</i>	0.10	3.36
American Basswood	<i>Tilia Americana</i>	0.09	2.86
White Ash	<i>Fraxinus Americana</i>	0.07	2.36
American Beech	<i>Fagus grandifolia</i>	0.06	2.16
Slippery Elm	<i>Ulmus rubra</i>	0.06	2.14
Eastern Red Cedar	<i>Juniperus virginiana</i>	0.06	1.92
Big-tooth Aspen	<i>Populus grandidentata</i>	0.06	1.85
Black Walnut	<i>Juglans nigra</i>	0.05	1.55
Chestnut Oak	<i>Quercus montana</i>	0.04	1.42
Sassafras	<i>Sassafras albidum</i>	0.04	1.41
Tamarack	<i>Larix laricina</i>	0.04	1.28
Common Serviceberry	<i>Amelanchier arborea</i>	0.04	1.21
Sycamore	<i>Platanus occidentalis</i>	0.04	1.19
White Pine	<i>Pinus strobus</i>	0.04	1.18
Mockernut Hickory	<i>Carya tomentosa</i>	0.03	0.95
Flowering Dogwood	<i>Cornus florida</i>	0.03	0.92
Pignut Hickory	<i>Carya glabra</i>	0.03	0.88
Tulip Poplar	<i>Liriodendron tulipifera</i>	0.02	0.58
Pitch Pine	<i>Pinus rigida</i>	0.02	0.52
Black Tupelo	<i>Nyssa sylvatica</i>	0.01	0.44
Black Oak	<i>Quercus velutina</i>	0.01	0.42
American Hornbeam	<i>Caprinus caroliniana</i>	0.01	0.41

Appendix VII Continued.

Native Understory-dominated Plots.

Common Name	Species Name	IV	IV%
Eastern Hemlock	<i>Tsuga Canadensis</i>	0.42	14.12
Black Birch	<i>Betula lenta</i>	0.39	12.94
Sugar Maple	<i>Acer saccharum</i>	0.34	11.37
Northern Red Oak	<i>Quercus rubra</i>	0.29	9.54
Red Maple	<i>Acer rubrum</i>	0.24	8.12
Black Cherry	<i>Prunus serotina</i>	0.17	5.67
Eastern Red Cedar	<i>Juniperus virginiana</i>	0.13	4.48
Scrub Oak	<i>Quercus ilicifolia</i>	0.11	3.78
White Oak	<i>Quercus alba</i>	0.10	3.42
Black Oak	<i>Quercus velutina</i>	0.07	2.37
Green Ash	<i>Fraxinus pennsylvanica</i>	0.06	2.13
Silver Maple	<i>Acer saccharinum</i>	0.06	2.09
Black Walnut	<i>Juglans nigra</i>	0.06	2.00
White Pine	<i>Pinus strobus</i>	0.06	1.99
Flowering Dogwood	<i>Cornus florida</i>	0.06	1.83
Black Tupelo	<i>Nyssa sylvatica</i>	0.05	1.79
Shagbark Hickory	<i>Carya ovata</i>	0.05	1.77
American Beech	<i>Fagus grandifolia</i>	0.05	1.76
Big-tooth Aspen	<i>Populus grandidentata</i>	0.05	1.51
Chestnut Oak	<i>Quercus montana</i>	0.04	1.32
Common Serviceberry	<i>Amelanchier arborea</i>	0.04	1.22
Sycamore	<i>Platanus occidentalis</i>	0.03	1.09
Slippery Elm	<i>Ulmus rubra</i>	0.03	0.84
European White Elm	<i>Ulmus laevis</i>	0.02	0.62
Pignut Hickory	<i>Carya glabra</i>	0.02	0.61
Mockernut Hickory	<i>Carya tomentosa</i>	0.02	0.61

Appendix VIII. Complete Sapling Ecological Importance Values by Plot Type.

Japanese Barberry-dominated Plots.

Common Name	Species Name	IV	IV%
Black Walnut	<i>Juglans nigra</i>	0.59	19.74
Sugar Maple	<i>Acer saccharum</i>	0.42	13.99
Yellow Birch	<i>Betula alleghaniensis</i>	0.28	9.17
American Hornbeam	<i>Caprinus caroliniana</i>	0.26	8.65
American Beech	<i>Fagus grandifolia</i>	0.24	7.88
Black Cherry	<i>Prunus serotina</i>	0.18	6.05
Black Birch	<i>Betula lenta</i>	0.15	4.95
Black Tupelo	<i>Nyssa sylvatica</i>	0.15	4.92
Tulip Poplar	<i>Liriodendron tulipifera</i>	0.13	4.31
Northern Red Oak	<i>Quercus rubra</i>	0.08	2.82
Eastern Red Cedar	<i>Juniperus virginiana</i>	0.07	2.31
Green Ash	<i>Fraxinus pennsylvanica</i>	0.07	2.29
American Hackberry	<i>Celtis occidentalis</i>	0.07	2.24
Red Maple	<i>Acer rubrum</i>	0.07	2.24
Mockernut Hickory	<i>Carya tomentosa</i>	0.07	2.17
Common Serviceberry	<i>Amelanchier arborea</i>	0.05	1.83
Sassafras	<i>Sassafras albidum</i>	0.05	1.70
Flowering Dogwood	<i>Cornus florida</i>	0.05	1.55

Appendix VIII Continued.

Transitional Plots.

Common Name	Species Name	IV	IV%
Black Birch	<i>Betula lenta</i>	0.53	17.54
American Beech	<i>Fagus grandifolia</i>	0.44	14.51
White Oak	<i>Quercus alba</i>	0.34	11.19
Sugar Maple	<i>Acer saccharum</i>	0.31	10.35
White Pine	<i>Pinus strobus</i>	0.25	8.18
Black Cherry	<i>Prunus serotina</i>	0.20	6.57
Northern Red Oak	<i>Quercus rubra</i>	0.13	4.41
Eastern Hemlock	<i>Tsuga Canadensis</i>	0.12	3.94
American Hornbeam	<i>Caprinus caroliniana</i>	0.10	3.44
Sassafras	<i>Sassafras albidum</i>	0.10	3.34
Tulip Poplar	<i>Liriodendron tulipifera</i>	0.09	2.87
Slippery Elm	<i>Ulmus rubra</i>	0.07	2.43
Eastern Red Cedar	<i>Juniperus virginiana</i>	0.06	2.00
Scrub Oak	<i>Quercus ilicifolia</i>	0.06	1.84
Red Maple	<i>Acer rubrum</i>	0.05	1.79
Common Serviceberry	<i>Amelanchier arborea</i>	0.05	1.60
Mockernut Hickory	<i>Carya tomentosa</i>	0.03	1.13
Norway Spruce	<i>Picea abies</i>	0.02	0.72
Black Walnut	<i>Juglans nigra</i>	0.02	0.55
Chestnut Oak	<i>Quercus montana</i>	0.02	0.53
Norway Maple	<i>Acer platanoides</i>	0.02	0.53
American Chestnut	<i>Castanea dentata</i>	0.02	0.53

Appendix VIII Continued.

Native Understory Plots.

Common Name	Species Name	IV	IV%
Black Birch	<i>Betula lenta</i>	0.59	19.58
American Beech	<i>Fagus grandifolia</i>	0.53	17.83
Black Cherry	<i>Prunus serotina</i>	0.34	11.26
Tulip Poplar	<i>Liriodendron tulipifera</i>	0.25	8.25
Eastern Hemlock	<i>Tsuga Canadensis</i>	0.22	7.34
Flowering Dogwood	<i>Cornus florida</i>	0.17	5.51
Sugar Maple	<i>Acer saccharum</i>	0.16	5.39
Scrub Oak	<i>Quercus ilicifolia</i>	0.15	5.01
White Pine	<i>Pinus strobus</i>	0.14	4.73
American Hornbeam	<i>Caprinus caroliniana</i>	0.13	4.28
Northern Red Oak	<i>Quercus rubra</i>	0.11	3.83
Mockernut Hickory	<i>Carya tomentosa</i>	0.10	3.46
Sassafras	<i>Sassafras albidum</i>	0.08	2.76
Chestnut Oak	<i>Quercus montana</i>	0.06	2.15
Red Maple	<i>Acer rubrum</i>	0.06	2.11
European White Elm	<i>Ulmus laevis</i>	0.06	2.07
White Oak	<i>Quercus alba</i>	0.06	1.86
Sycamore	<i>Cornus florida</i>	0.06	1.84
Common Serviceberry	<i>Amelanchier arborea</i>	0.04	1.36
Black Oak	<i>Quercus velutina</i>	0.03	0.87

Appendix IX. Complete Shrub Ecological Importance Values by Plot Type.

Japanese Barberry-dominated Plots.

Common Name	Species Name	IV	IV%
Japanese Barberry	<i>Berberis thunbergii</i>	1.26	63.15
Multiflora Rose	<i>Rosa multiflora</i>	0.31	15.46
Spicebush	<i>Lindera benzoin</i>	0.15	7.37
Autumn Olive	<i>Elaeagnus umbellata</i>	0.08	3.94
Japanese Wisteria	<i>Wisteria floribunda</i>	0.07	3.59
Lowbush Blueberry	<i>Vaccinium angustifolium</i>	0.03	1.53
Common Lilac	<i>Syringa vulgaris</i>	0.02	0.92
Northern Dewberry	<i>Rubus flagellaris</i>	0.02	0.92
Burning Bush	<i>Euonymus alatus</i>	0.02	0.80
European Privet	<i>Ligustrum vulgare</i>	0.02	0.80
Japanese Wineberry	<i>Rubus phoenicolasius</i>	0.02	0.80
Japanese Honeysuckle	<i>Lonicera japonica</i>	0.01	0.71

Appendix IX Continued.

Transitional Plots.

Common Name	Species Name	IV	IV%
Japanese Barberry	<i>Berberis thunbergii</i>	0.73	36.64
Spicebush	<i>Lindera benzoin</i>	0.48	23.86
Highbush Blueberry	<i>Vaccinium corymbosum</i>	0.24	12.10
Multiflora Rose	<i>Rosa multiflora</i>	0.14	6.92
Japanese Wisteria	<i>Wisteria floribunda</i>	0.11	5.59
Lowbush Blueberry	<i>Vaccinium angustifolium</i>	0.09	4.26
Burning Bush	<i>Euonymus alatus</i>	0.07	3.44
Tree of Heaven	<i>Ailanthus altissima</i>	0.05	2.42
Northern Dewberry	<i>Rubus flagellaris</i>	0.03	1.29
Common Greenbrier	<i>Smilax rotundifolia</i>	0.02	0.96
Autumn Olive	<i>Elaeagnus umbellata</i>	0.02	0.86
European Privet	<i>Ligustrum vulgare</i>	0.02	0.83
Japanese Wineberry	<i>Rubus phoenicolasius</i>	0.02	0.83

Appendix IX Continued.

Native Understory-dominated Plots.

Common Name	Species Name	IV	IV%
Spicebush	<i>Lindera benzoin</i>	0.70	34.77
Lowbush Blueberry	<i>Vaccinium angustifolium</i>	0.48	23.89
Japanese Barberry	<i>Berberis thunbergii</i>	0.18	9.20
Autumn Olive	<i>Elaeagnus umbellata</i>	0.13	6.64
Mountain Laurel	<i>Kalmia latifolia</i>	0.14	6.85
Northern Dewberry	<i>Rubus flagellaris</i>	0.11	5.46
Rosebay Rhododendron	<i>Rhododendron maximum</i>	0.07	3.29
Highbush Blueberry	<i>Vaccinium corymbosum</i>	0.05	2.75
Japanese Wisteria	<i>Wisteria floribunda</i>	0.05	2.75
Multiflora Rose	<i>Rosa multiflora</i>	0.04	2.20
Japanese Wineberry	<i>Rubus phoenicolasius</i>	0.04	2.20

Appendix X. Complete Bird Species Observation List for 2016 and 2017 Field Seasons.

Common Name	Species Name
Canada Goose	<i>Branta canadensis</i>
Mute Swan	<i>Cygnus olor</i>
Wood Duck	<i>Aix sponsa</i>
Mallard	<i>Anas platyrhynchos</i>
Hooded Merganser	<i>Lophodytes cucullatus</i>
Common Merganser	<i>Mergus merganser</i>
Wild Turkey	<i>Meleagris gallopavo</i>
Great Blue Heron	<i>Ardea herodias</i>
Green Heron	<i>Butorides virescens</i>
Black Vulture	<i>Coragyps atratus</i>
Turkey Vulture	<i>Cathartes aura</i>
Osprey	<i>Pandion haliaetus</i>
Cooper's Hawk	<i>Accipiter cooperii</i>
Sharp-shinned Hawk	<i>Accipiter striatus</i>
Bald Eagle	<i>Haliaeetus leucocephalus</i>
Red-shouldered Hawk	<i>Buteo lineatus</i>
Broad-winged Hawk	<i>Buteo platypterus</i>
Red-tailed Hawk	<i>Buteo jamaicensis</i>
Killdeer	<i>Charadrius vociferous</i>
Spotted Sandpiper	<i>Actitis macularius</i>
Solitary Sandpiper	<i>Tringa solitaria</i>
Mourning Dove	<i>Zenaida macroura</i>
Yellow-billed Cuckoo	<i>Coccyzus americanus</i>
Black-billed Cuckoo	<i>Coccyzus erythrophthalmus</i>
Barred Owl	<i>Strix varia</i>
Chimney Swift	<i>Chaetura pelagica</i>
Ruby-throated Hummingbird	<i>Archilochus colubris</i>
Belted Kingfisher	<i>Megaceryle alcyon</i>
Red-bellied Woodpecker	<i>Melanerpes carolinus</i>
Downy Woodpecker	<i>Picoides pubescens</i>
Hairy Woodpecker	<i>Picoides villosus</i>
Northern Flicker	<i>Colaptes auratus</i>
Pileated Woodpecker	<i>Dryocopus pileatus</i>
American Kestrel	<i>Falco sparverius</i>
Eastern Wood-Pewee	<i>Conotous virens</i>
Acadian Flycatcher	<i>Empidonax virescens</i>
Eastern Phoebe	<i>Sayornis phoebe</i>

Appendix X Continued.

Common Name	Species Name
Great Crested Flycatcher	<i>Myiarchus crinitus</i>
Eastern Kingbird	<i>Tyrannus tyrannus</i>
White-eyed Vireo	<i>Vireo griseus</i>
Yellow-throated Vireo	<i>Vireo flavifrons</i>
Blue-headed Vireo	<i>Vireo solitarius</i>
Warbling Vireo	<i>Vireo gilvus</i>
Red-eyed Vireo	<i>Vireo olivaceus</i>
Blue Jay	<i>Cyanocitta cristata</i>
American Crow	<i>Corvus brachyrhynchos</i>
Fish Crow	<i>Corvus ossifragus</i>
Common Raven	<i>Corvus corax</i>
Northern Rough-winged Swallow	<i>Steligidopteryx serripennis</i>
Tree Swallow	<i>Tachycineta bicolor</i>
Bank Swallow	<i>Riparia riparia</i>
Barn Swallow	<i>Hirundo rustica</i>
Cliff Swallow	<i>Petrochelidon pyrrhonota</i>
Black-capped Chickadee	<i>Poecile atricapillus</i>
Tufted Titmouse	<i>Baeolophus bicolor</i>
Red-breasted Nuthatch	<i>Sitta canadensis</i>
White-breasted Nuthatch	<i>Sitta carolinensis</i>
Brown Creeper	<i>Certhia Americana</i>
House Wren	<i>Troglodytes aedon</i>
Winter Wren	<i>Troglodytes hiemalis</i>
Carolina Wren	<i>Thryothorus ludovicianus</i>
Blue-gray Gnatcatcher	<i>Polioptila caerulea</i>
Golden-crowned Kinglet	<i>Regulus satrapa</i>
Ruby-crowned Kinglet	<i>Regulus calendula</i>
Swainson's Thrush	<i>Catharus ustulatus</i>
Veery	<i>Catharus fuscescens</i>
Hermit Thrush	<i>Catharus guttatus</i>
Wood Thrush	<i>Hylocichla mustelina</i>
American Robin	<i>Turdus migratorius</i>
Gray Catbird	<i>Dumetella carolinensis</i>
Brown Thrasher	<i>Toxostoma rufum</i>
Northern Mockingbird	<i>Mimus polyglottos</i>
European Starling	<i>Sturnus vulgaris</i>
Cedar Waxwing	<i>Bombycilla cedrorum</i>
Ovenbird	<i>Seiurus aurocapilla</i>
Worm-eating Warbler	<i>Helmitheros vermivorum</i>
Louisiana Waterthrush	<i>Parkesia motacilla</i>

Appendix X Continued.

Common Name	Species Name
Northern Waterthrush	<i>Parkesia noveboracensis</i>
Blue-winged Warbler	<i>Vermivora cyanoptera</i>
Black-and-white Warbler	<i>Mniotilta varia</i>
Tennessee Warbler	<i>Oreothlypis peregrina</i>
Nashville Warbler	<i>Oreothlypis ruficapilla</i>
Common Yellowthroat	<i>Geothlypis trichas</i>
Hooded Warbler	<i>Setophaga citrina</i>
American Redstart	<i>Setophaga ruticilla</i>
Cape May Warbler	<i>Setophaga tigrina</i>
Cerulean Warbler	<i>Setophaga cerulean</i>
Northern Parula	<i>Setophaga americana</i>
Magnolia Warbler	<i>Setophaga magnolia</i>
Blackburnian Warbler	<i>Setophaga fusca</i>
Yellow Warbler	<i>Setophaga petechial</i>
Chestnut-sided Warbler	<i>Setophaga pensylvanica</i>
Blackpoll Warbler	<i>Setophaga striata</i>
Black-throated Blue Warbler	<i>Setophaga caerulescens</i>
Pine Warbler	<i>Setophaga pinus</i>
Yellow-rumped Warbler (Myrtle)	<i>Setophaga coronata</i>
Prairie Warbler	<i>Setophaga discolor</i>
Black-throated Green Warbler	<i>Setophaga virens</i>
Canada Warbler	<i>Cardellina canadensis</i>
Chipping Sparrow	<i>Spizella passerina</i>
Field Sparrow	<i>Spizella pusilla</i>
Dark-eyed Junco	<i>Junco hyemalis</i>
White-throated Sparrow	<i>Zonotrichia albicollis</i>
Song Sparrow	<i>Melospiza melodia</i>
Swamp Sparrow	<i>Melospiza georgiana</i>
Eastern Towhee	<i>Pipilo erythrophthalmus</i>
Scarlet Tanager	<i>Piranga olivacea</i>
Northern Cardinal	<i>Cardinalis cardinalis</i>
Rose-breasted Grosbeak	<i>Pheucticus ludovicianus</i>
Indigo Bunting	<i>Passerina cyanea</i>
Orchard Oriole	<i>Icterus spurius</i>
Baltimore Oriole	<i>Icterus galbula</i>
Red-winged Blackbird	<i>Agelaius phoeniceus</i>
Brown-headed Cowbird	<i>Molothrus ater</i>
Common Grackle	<i>Quiscalus quiscula</i>
House Finch	<i>Haemorhous mexicanus</i>
American Goldfinch	<i>Spinus tristis</i>
House Sparrow	<i>Passer domesticus</i>

Appendix XI. Photographs.



ASY male Hooded Warbler with horsefly (*Tabanus* sp.) banded on 7 June 2016 in the transitional plot of block one. Photograph by Stephen Kloiber.



HOWA nest in Japanese Barberry-dominated plot of block three, 18 May 2017. Photograph by Terry Master.



Photograph of SY male HOWA, showing molt limit in the primary coverts. 23 May 2017 in the transitional plot of block three. Photograph by B. Swayser

Appendix XI Continued.



SY female HOWA
banded in transitional
plot of block four on 11
May 2016. Photograph
by B. Swayser



ASY Female HOWA, showing
darkened male-like hood
typical of an older female.
Photograph taken in
transitional plot of block six
on 11 May 2017 by B.
Swayser



Female HOWA on nest in
Japanese Barberry-dominated
plot of block three.
Photograph taken from afar
with heavy zoom, on 27 May
2017 by B. Swayser