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Abstract: The introduction of European starlings (*Sturnus vulgaris*) in New York City in 1890 and 1891 resulted in their permanent establishment in North America. The successful occupation of North America (and most other continents as well) has earned the starling a nomination in the Top 100 list of ‘Worlds Worst’ invaders. Pimentel et al. (2000) estimated that starling damage to agriculture crops in the United States was $800 million yearly, based on $5/ha damage. Starlings may spread infectious diseases that sicken humans and livestock, costing nearly $800 million in health treatment costs. Lastly, starlings perhaps have contributed to the decline of native cavity-nesting birds by usurping their nesting sites. We describe the life history of starlings, their economic impact on agriculture, and their potential role as vectors in spreading diseases to livestock and humans. We recommend that the database on migratory and local movements of starlings be augmented and that improved baits and baiting strategies be developed to reduce nuisance populations.

Key Words: agricultural damage, disease, European starling, invasive species, livestock, *Sturnus vulgaris*, urban wildlife.

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INTRODUCTION

The European starling (*Sturnus vulgaris*) has been nominated by the Invasive Species Specialist Group to the "100 World's Worst" invaders (Lowe et al. 2004). Only two other bird species, the common myna (*Acridotheres tristis*) and red-vented bulbul (*Pycnonotus cafer*), have been nominated for this list. In this paper, we review the biology and ecology behind the European starling’s phenomenal adaptive abilities. We also describe case studies of damage caused by starlings and overall economic impact. We focus on the European starlings (henceforth, starlings) in North America, but acknowledge that starlings have been introduced into or invaded most other continents as well, and likewise have become a successfully established pest species around the world.

THE INVASION

The European starling’s native range is Europe, southwest Asia and northern Africa. It was introduced into North America, South Africa, New Zealand, and Australia because of cultural longings of new immigrants and false perceptions of biological control of insects (Adeney 2001). Becoming a viable invading population is not always easy, even for a species as highly adapted to human environments as the starling. In North America, many attempts were made at introduction. In the mid- to late nineteenth century, people in both Oregon and New York tried repeatedly. Starlings eventually took hold in New York City, where 16 pairs survived a 50-pair release in 1890 and 1891. The descendants of these survivors expanded their population rapidly westward, reaching the West Coast in 1942 (see Cabe 1993, for an excellent review of this species). It is believed that most or all of the starlings now inhabiting North America (from Florida to Alaska), the Bahamas, Central America, Yucatan Peninsula, Puerto Rico, Jamaica, and Cuba are from the original 16 pairs that colonized New York City. North America's population is estimated at 200 million, about one-third of the world's starling population (Feare 1984). According to route counts from the North American Breeding Bird Survey, only red-winged blackbirds (*Agelaius phoeniceus*) out-number starlings (US Geological Survey 2005).

IDENTIFICATION

In breeding plumage, this small bird (70-100 g) has iridescent green feathers that cover the nape, breast and back; whereas, their pointed, triangular, black wings (31-40 cm long) have a green or purple sheen. The bill color helps distinguish the sexes during the breeding season. Both genders have a bright yellow beak; however, the lower mandible is blue-gray in males and pink in females during the breeding season. Uniform brown eyes are typical of males; the female has a narrow and light-colored iris. Mass of males (73-96 g) and females (69-93 g) overlap to the point that this metric is unreliable for distinguishing between genders (Blem 1981).

REPRODUCTION AND CARE OF YOUNG

Once established at a site, starlings have a high degree of breeding site fidelity. Kessel (1957) found that about 30% of females used the same nest box in successive years, and about 90% moved less than 1 km to breed. The young-of-the-year disperse widely and find new breeding sites, often far away from their natal site. Eggs are laid from late March to early July, depending on latitude. Nest sites are in natural cavities or in various nooks and crannies of man-made structures. Most starlings produce 1 to 2 clutches per year of 4-6 eggs each, with birds above 48^0 N producing only one clutch (Craig and Feare 1999). Eggs are incubated for about 12 days before hatching (Ricklefs and Smeraski 1983). Experiments have shown that if the first egg is removed, females sometimes continue laying in an attempt to complete the clutch (Meijer 1990); at other times, they do not replace the removed first egg (Kennedy and Power 1990). The incubation period lasts for about 12 days. The eggs are incubated for 18-19 hours per day, and up to 23 hours per day during cold periods. The female does about 70% of the incubation during the day and all of it at night (Drent et al. 1985). As a result of nest parasitism, up to 33% of the nestlings are not genetic siblings (Pinxten et al. 1987, Power et al. 1989, Romagnano et al. 1990). Parents bring food to the nest up to 20 times per hour. Nestlings show fear by day 12, and thermoregulate by day 13 (Johnson and Cowan 1974). It takes about 3 weeks for nestlings to fledge. The parents continue feeding the fledglings for another 4-10 days before complete independence is achieved. The average life span is about 2-3 years, with a longevity record of over 20 years.

FOODS

Starlings eat plant matter and invertebrates, with the latter being favored during the spring and summer months, when they are readily available. Starlings feed on a wide variety of invertebrates, including beetles, millipedes, butterfly and moth larvae, grasshoppers, and crickets (Tinbergen 1981). Starlings forage in fruit orchards, especially in the fall. In the winter, particularly when the ground is snow-covered or frozen, they frequent feedlots, dairies, and urban landfills, where food is abundant. Starlings often join large roosting aggregations that exploit a nutritious and abundant food source (Morrison and Caccamise 1990, Caccamise 1991). Once established at a preferred feeding site, they may be hard to dissuade from it and will endure tremendous efforts by humans at keeping them away. In caged trials, researchers found that starlings eat 7-23 g of animal food daily and 20-40 g of plant food (Feare 1984). Fischl and Caccamise (1987) found that plant food made up 62% of starlings' diet by dry weight; 21% was animal matter, but this ratio varies seasonally.

POPULATION DYNAMICS AND MORTALITY FACTORS

Starlings are prolific and have a 48% to 79% rate of nest success (Kessel 1957, Royall 1966). Even so, only 20% nestlings survive to reproduce (Kessel 1957). Adult survival is much higher, probably around 60% (Flux and Flux 1981). It is not known what is limiting the starling population in North America. Starlings carry a heavy parasite load, including lice, mites and ticks, flatworms and round worms, all of which affect mortality rates (Boyd 1951). Cold and wet weather and extreme hot weather can contribute to mortality of nestlings, with both factors affecting the availability of an important food source, temperature sensitive invertebrates (Gromadzki 1980, Tinbergen 1981).

Occasionally, squirrels access nests and destroy entire clutches (Feare 1984). Finally, large numbers of starlings are trapped and poisoned to protect agriculture, livestock, and urban and industrial structures, but this probably has little impact on the overall population (Homan et al. 2005). Availability of nesting sites may limit the populations.

MIGRATION

Starlings are strong flyers and can, if necessary, migrate distances of 1,000-1,500 km, especially to escape heavy snow that covers food sources. They can migrate long distances in a single day at speeds of 60-80 km/h (Feare 1984), stopping to forage along the way. Migration patterns vary by year, by region, and by individual (Kessel 1953, Suthers 1978). Starlings south of 40° N rarely migrate (Dolbeer 1982). Spring migration occurs from mid-February to late March and fall migration from September to early December (Kessel 1953, Dolbeer 1982).

DISEASE TRANSMISSION

Starlings carry a plethora of diseases (Weber 1979, Gautsch et al. 2000, Clark and McLean 2003, Table 1). Avian salmonellosis (primarily, *Salmonella enterica*) has been documented in starlings (Feare 1984). This disease is transmissible to humans, poultry, and livestock. Chlamydiosis (also psittacosis, ornithosis, parrot fever) usually results from inhaling *Chlamydophila psittaci* that lives in dried feces. Starlings and blackbirds can infect humans and domestic fowl with *C. psittaci* (Grimes 1978, Grimes et al. 1979, Andersen et al. 1997). Starlings also carry *Mycobacterium avium paratuberculosis*, which causes Johne's disease in cattle (also known as paratuberculosis) (Matthews and McDiarmid 1979, Corn et al. 2005). The bacteria are excreted in feces and milk. Johne's disease costs the United States (US) dairy industry $200-250 million, annually (Beard et al. 2001, Ott et al. 1999). Starling fecal matter can pass transmissible gastroenteritis (TGE) to swine. Although the evidence is largely indirect and circumstantial, it is believed that during the winter of 1978-1979 starlings served as vectors for an outbreak of TGE in Nebraska that caused the loss of 10,000 swine in one month (Pilchard 1965, Bohl 1975, Gough et al. 1979, Johnson and Glahn 1994). Shiga toxin-producing *Escherichia coli* (STEC) is another disease the may be transmitted by starlings to cattle. In the cattle industry, annual costs of illnesses related to E. coli STEC exceeded $267 million (NCBA 2004). Humans get this disease when consuming tainted food products, especially ground beef. Knowledge of the movement patterns of starlings would be critical to understanding the real role that starlings have in epidemiologies of these diseases.

By disturbing soil or flooring at blackbird and starling roosts, humans can become ill with histoplasmosis, a fungal disease of the lungs caused by *Histoplasma capsulatum* (DiSalvo and Johnson 1979, Storch et al. 1980). Histoplasmosis recently was reported at a manufacturing facility in Nebraska used by starlings (J. Hobbs, personal communication). People at highest risk of exposure, however, are those working in agriculture, particularly poultry, or those coming in contact with bird or bat roosts that might have been abandoned a decade or more prior to disturbance (DiSalvo and Johnson 1979). Finally, West Nile virus (WNV) was confirmed in North America in 1999 and since that time has spread across the US. This is a serious, and life-threatening disease to humans and wildlife. Sullivan et al. (2006) found that red-winged blackbirds are WNV hosts and can disperse diseases along their migratory routes. The role of starlings in dispersing WNV is unknown, but starlings can act as hosts for the virus (Bernard et al. 2001), and thus may be involved in spreading the disease among vertebrates including, humans, horses, and birds.

ECONOMIC IMPACTS

Pimentel et al. (2000) estimated that yearly starling damage to agriculture was US$800 million, based on a figure of US$5/ha. In 1999, three feedlot operators in Kansas estimated a loss of $600,000 from bird damage alone (US Department of Agriculture 2000). Data reported in 1968 from Colorado feedlots indicated the cost of cattle rations consumed during winter by starlings was $84 per 1,000 starlings. With the current cost of feed, the associated losses would certainly be much higher. In Idaho, some livestock facility operators estimated that starlings consumed 15 to 20 tons of cattle feed per day. The costs associated with starlings in the spread of livestock disease may be more important than food consumption. For example, the 10,000 pigs lost in Nebraska might be valued at nearly US$1.0 million in today's market.

Table 1. Information on some diseases transmissible to humans and livestock that are associated with feral domestic pigeons, European starlings, and English sparrows. Data originally from Weber (1979) and accessed in numerous Wildlife Services' Environmental Assessments.

Disease	Livestock Affected	Symptoms	Comments
Bacterial:			
Erysipeloid	Cattle, swine, horses, sheep, goats, chickens, turkeys, ducks	Pigs - arthritis, skin lesions, necrosis, septicemia Sheep - lameness	Serious hazard for the swine industry, rejection of swine meat at slaughter due to speticemia, also affects dogs
Salmonellosis	All domestic animals	Abortions in mature cattle, mortality in calves, decrease in milk production in dairy cattle Colitis in pigs,	Over 1,700 serotypes
Pasteurellosis	Cattle, swine, horses, rabbits, chickens, turkeys	Chickens and turkeys die suddenly without illness pneumonia, bovine mastitis, abortions in swine, septicemia, abscesses	Also affects cats and dogs
Avian tuberculosis	Chickens, turkeys, swine, cattle, horses, sheep	Emaciation, decrease in egg production, and death in poultry. Mastitis in cattle	Also affects dogs and cats
Streptococcosis	Cattle, swine, sheep, horses, chickens, turkeys, geese, ducks, rabbits	Emaciation and death in poultry. Mastitis in cattle, abscesses and inflamation of the heart, and death in swine	Feral pigeons are susceptible and aid in transmission
Yersinosis	Cattle, sheep, goats, horses, turkeys, chickens, ducks	Abortion in sheep and cattle	Also affects dogs and cats
Vibriosis	Cattle and sheep	In cattle, often a cause of infertility or early embryonic death. In sheep, the only known cause of infectious abortion in late pregnancy	Of great economic importance

Table 1. Continued

Disease	Livestock Affected	Symptoms	Comments
Bacterial (continued):			
Listeriosis	Chickens, ducks, geese, cattle, horses, swine, sheep, goats	In cattle, sheep, and goats, difficulty swallowing, nasal discharge, paralysis of throat and facial muscles	Also affects cats and dogs
Viral:			
Meningitis	Cattle, sheep, swine, poultry	Inflammation of the brain, newborn calves unable to suckle	Associated with listeriosis, salmonellosis, cryptococcosis
Encephalitis (7 forms)	Horses, turkeys, ducks	Drowsiness, inflammation of the brain	Mosquitos serve as vectors
Mycotic (fungal):			
Aspergillosis	Cattle, chickens, turkeys, ducks	Abortions in cattle	Common in turkey poults
Blastomycosis	Weight loss, fever, cough, bloody sputum, chest pains.	Rarely	Affects horses, dogs and cats
Candidiasis	Cattle, swine, sheep, horses, chickens, turkeys	In cattle, mastitis, diarrhea, vaginal discharge, and aborted fetuses	Causes unsatisfactory growth in chickens
Cryptococcosis	Cattle, swine, horses	Chronic mastitis in cattle, decreased milk flow and appetite loss	Also affects dogs and cats
Histoplasmosis	Horses, cattle, swine	Chronic cough (in dogs), loss of appetite, weakness, depression, diarrhea, extreme weight loss	Also affects dogs; actively grows and multiplies in soil and remains active long after birds have departed
Coccidiosis	Poultry, cattle, and sheep	Bloody diarrhea in chickens, dehydration, retardation of growth	Almost always present in English sparrows; also found in pigeons and European starlings

Table 1. Continued.

Disease	Livestock Affected	Symptoms	Comments
Protozoal:			
American trypanosomiasis	Infection of mucous membranes of eyes or nose, swelling	Possible death in 2-4 weeks	Caused by the conenose bug found on pigeons
Toxoplasmosis	Cattle, swine, horses, sheep, chickens, turkeys	In cattle, muscular tremors, coughing, sneezing, nasal discharge, frothing at the mouth, prostration and abortion	Also affects dogs and cats
Rickettsial/Chlamydial:			
Chlamydiosis	Cattle, horses, swine, sheep, goats, chickens, turkeys, ducks, geese	In cattle, abortion, arthritis, conjunctivitis, enteritis	Also affects dogs, cats, and many wild birds and mammals
Q fever	Affects cattle, sheep, goats, and poultry	May cause abortions in sheep and goats	Can be transmitted by infected ticks

Starlings also damage fruit and grain crops (Johnson and Glahn 1994). Bird damage to grapes in the US was estimated to be at least $4.4 million in 1972; and starlings were one of the species that caused the most damage. Starlings also damage ripening cherry crops. A 1972 study in Michigan found 17% of a total crop was lost. Starlings damage other cultivated fruit crops, such as peaches, blueberries, strawberries, figs, and apples. Although not a major consumer of cereal grains, starlings have damaged winter wheat and ripening corn. In Kentucky and Tennessee, starling damage to winter wheat averaged 1.6%, with higher losses occurring near roosts.

Starling roosts near airports pose an aircraft safety hazard because of the potential for birds to be ingested into jet engines, resulting in aircraft damage or loss and, at times, injury and loss of human life. Starlings have caused some of the most disastrous bird-aircraft strikes due to their body density and flocking behavior. Starlings caused an Electra aircraft to crash in Boston in 1960 that killed 62 people. Barras et al. (2003) reported that during 1990-2001, 852 strikes involving blackbirds and starlings were reported to the FAA from 46 States and the District of Columbia. Damage was reported in 39 strikes and damage was unknown in 215 strikes; costs totaled $1,607,317. Although only about 6% of bird-aircraft strikes are associated with starlings or blackbirds, these species represent a substantial management challenge at airports.

The use of urban areas by wintering flocks of starlings seeking warmth and shelter for roosting can have serious consequences. Large roosts in buildings and industrial structures cause filth, noise, odor, and health and safety hazards. Additionally, the droppings are corrosive to infrastructure. In the early 2000s, a large population in Omaha used a bank building as a roost, costing $200,000 in cleanup costs. Nebraska Wildlife Service's (WS) provided technical training for executing an effective starling harassment strategy that significantly lowered the roosting population at the bank. Moreover, WS augmented this effort by managing the Omaha starling population with DRC-1339 avicide. Similarly, downtown Indianapolis had a problem with roosting starlings during winter. Thousands of starlings were using the downtown area. City managers funded WS to conduct a successful comprehensive harassment program (J. Loven, personal communication). To date, population management has not been deemed necessary by the citizens of Indianapolis.

ECOLOGICAL IMPACTS

Starlings compete aggressively with native cavity-nesting birds for nest sites. However, Koenig (2003) used Christmas Bird Counts and Breeding Bird Surveys and found the effects of starlings on populations of 27 cavity-nesting species to be practically nonexistent. He did conclude that sapsuckers (*Sphyrapicus* spp.) may have declined because of starling competition for nest sites.

MANAGEMENT

The most universal technique of managing nuisance populations of starlings is by harassing them with propane exploders, pyrotechnics, hawk kites, and ultrasonic sounds. Unfortunately, the results from these nonlethal techniques are usually temporary, unless they are intense, sustained, and varied. In addition to physical frightening agents, the chemical frightening agent, 4-aminopyridine (Avitrol®) is sometimes used. It is a restricted use pesticide available only to certified applicators. Avitrol® baits contain a small number of treated grains or pellets that are diluted with untreated grains or pellets. Birds that eat the treated baits behave erratically and give warning cries that frighten other birds from the area. Any bird, target or non-target, that eats a 4-aminopyridine treated particle could die. In theory, hawks and owls that eat affected or dead birds that have ingested this agent also could die. Polybutenes, formulated under trade names such as Roost-No-More®, Bird Tanglefoot®, and 4-The-Birds®, are sticky materials that might discourage starlings from roosting on ledges and beams. Labor-costs and longevity are issues that managers must consider when using these nonlethal products. Finally, dimethyl anthranilate (DMA) and methyl anthranilate (MA) are taste aversive compounds that repel starlings under experimental conditions in feedlots and fruit production facilities, but apparently are not widely used for that purpose (Glahn et al. 1989). Trapping is common in some areas, followed by euthanasia.

Lethal chemical control of starling populations is achieved with DRC-1339 (3-chloro-4-methylaniline hydrochloride, also 3-chloro p-toluidine hydrochloride, 3-chloro-4-methylaniline). This avicide was first used to control starlings and blackbirds in livestock feedlots of the intermountain region of the western US (DeCino et al. 1966, Royall et al. 1967, West 1968). According to Besser et al. (1967), a starling population was reduced by about 75% after spreading 1% DRC-1339-treated poultry pellets at a cattle feedlot in Nevada. A roost of approximately 250,000 starlings in Colorado was reduced by more than 60% by baiting a feedlot and a pasture (West 1968).

Starlicide, a DRC-1339 product, is a slow-acting toxicant for controlling starlings and blackbirds around livestock and poultry operations. It is toxic to other types of birds in differing amounts, but will not kill many members of the family Emberizidae at registered levels. Mammals are generally resistant to its toxic effects. Poisoned birds experience a slow, nonviolent death. They usually die from 1 to 3 days after feeding, often at their roost. Generally, few dead starlings will be found at the bait site. Poisoned starlings are not dangerous to scavengers or predators as the chemical is quickly metabolized and excreted (Eisemann et al. 2003).

RESEARCH NEEDS

The reproductive biology of starlings is well documented, but data on regional migratory patterns and local movements in relation to feedlots, diaries, and urban areas are needed. Scientists for USDA Wildlife Services, in collaboration with North Dakota State University, The Ohio State University, and others are beginning to gather these data. This information will be useful for developing risk assessments and economic impact models that will help determine the overall consequences of a burgeoning population of starlings. Finally, efforts are underway to develop and evaluate better bait carriers for the compound DRC-1339 baits. Finally, better information is needed to determine their role in transmitting diseases.

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