When avifauna collide: the case for lethal control of barred owls in western North America

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Forest avifauna in eastern North America have expanded their range across the Great Plains to the West, likely due to anthropogenic changes. The barred owl (*Strix varia*) is a focal example of the negative effects that these intracontinental range expansions can have, with this invasive species becoming a major threat to the northern spotted owl (*Strix occidentalis caurina*) and potentially larger biological communities. If barred owl populations are not managed immediately, northern spotted owl populations will likely be extirpated from large parts of their range and, ultimately, may become extinct. Of available management options, lethal control of barred owls has the greatest potential to rapidly benefit spotted owls and other impacted species. We argue that immediate action is necessary to buy time while other management options are explored and developed and that lethal control is an ethical management option. The barred owl conundrum exemplifies the challenges of managing native invasive species.

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Historically, the North American Great Plains were a barrier separating the eastern forest avifauna from their western counterparts in North America (Mengel 1964; Engle *et al.* 2008; Livezey 2009b). However, in the past century, this once almost impenetrable barrier has become freckled with forest patches and corridors created by anthropogenic changes, including fire suppression, planting of urban shade trees, promotion of riparian woodlands after the removal of bison (*Bison bison*) and beaver (*Castor canadensis*), and establishing windbreaks after the Dust Bowl (Engle *et al.* 2008; Livezey 2009b; Currey *et al.* 2022). These changes allowed forest-dependent eastern avifauna to "island hop" or follow riparian forest corridors across the once treeless expanse of grasslands to interact and compete with ecologically similar forest species of the West, which had been separated from their eastern counterparts for millennia (DeSante and George 1994; La Sorte and Boecklen 2005).

In a nutshell:

- In response to anthropogenic climate change and habitat alteration, animals are shifting their geographic ranges, sometimes with negative effects on the ecological communities therein
- Barred owls (*Strix varia*) from the eastern US have expanded to the West and will need to be managed effectively to prevent the extinction of the federally listed northern spotted owl (*Strix occidentalis caurina*)
- In North America, as the fauna mix, difficult decisions on management will need to be made

An invasive species is an organism that causes ecological or economic harm in an environment where it is not native, whereas native invaders are species that have become invasive by expanding their range into new areas through anthropogenic modifications (Carey *et al.* 2012). The perception is usually that an invasive species on one continent originated from a different continent; however, increasingly, invasive species are native to a continent but expanded their historical geographic range into new environments in response to anthropogenic changes. These shifts in species' geographic ranges may result in a collision course with native species that are naïve to the invading species. For example, the blue jay (*Cyanocitta cristata*) expanded its range from eastern to western North America within approximately the past 70 years (Figure 1). Although their impacts on western forest avifauna are largely unknown, invasive blue jays are predicted to have negative effects on several native avian species because they are aggressive nest predators of many species, especially songbirds (Danielson *et al.* 1997), and could be potential competitors with native corvids. For instance, in Massachusetts, Kluza *et al.* (2000) found that blue jay populations increased with human housing density, which correlated with declines in open-cup-nesting bird populations. Invasive blue jays have also been implicated in the local extirpation of endangered golden-cheeked warbler (*Setophaga chrysoparia*) populations in Texas (Engels and Sexton 1994). In addition, invasive blue jays may impact the ecology of West Nile virus in western North America because they are considered a competent amplifying host for the virus (LaDeau *et al.* 2008), accounting for 22% of viral amplification in some areas (Levine *et al.* 2016).

Range expansions can also lead to "conservation conundrums" for impacted species that are already threatened or

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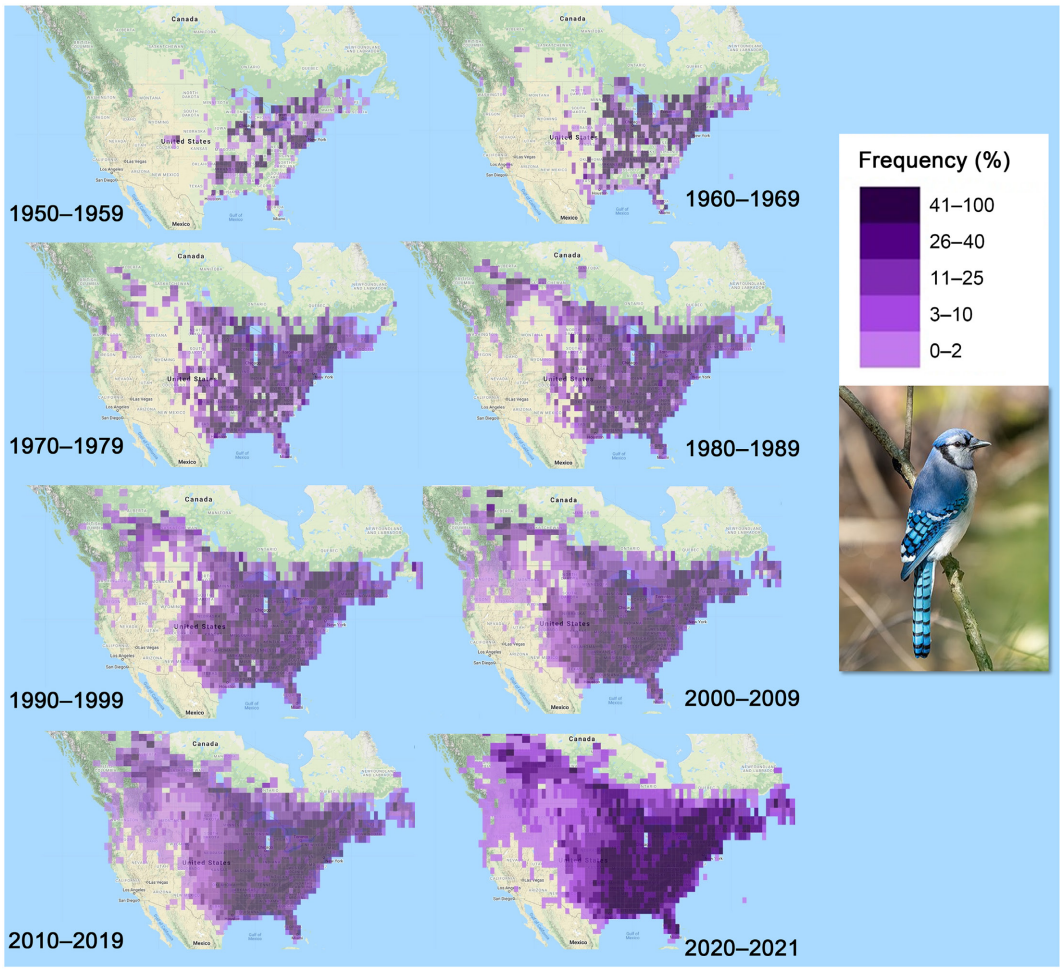

Figure 1. Blue jay (*Cyanocitta cristata*) range expansion from eastern to western North America from 1950 through 2021. Data are from observations compiled by eBird (www.ebird.org). Maps were generated within the eBird website (see Data Availability Statement). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the Cornell Laboratory of Ornithology. Image credit (blue jay): Rhododendrites/Wikipedia (CCA-SA 4.0 International license).

endangered. In one increasingly dire situation, the detrimental effects of one eastern US species, the barred owl (*Strix varia*), on native forest species of the western US have been well documented (Holm *et al.* 2016). Barred owls have negatively impacted threatened populations of spotted owls (*Strix occidentalis*) to such an extent that some spotted owl populations are nearly, or likely soon to be, extirpated. Here, we use the barred owl as an example of the consequences of shifts in avifaunal distributions across North America, of how barred owls can negatively impact other species, and of the resulting conservation conundrums and difficult choices that managers face, including lethal removal of invasives. Our goal is not to outline a comprehensive strategy for barred owl management, but rather to establish the importance of dealing swiftly and decisively with native invasive species.

Human activity facilitated the western movement of barred owls

Barred owls are large, charismatic, forest owls, with a historical range primarily restricted to the eastern US by the presence of the Great Plains (Figure 2). Although rare vagrants or small populations may have occurred in forest patches in eastern Montana and northeastern Colorado as early as the late 1800s, records in western North America have since become more reliable and show that barred owl numbers substantially increased in the early to mid-1900s (Livezey 2009a). Over the past 70 years, the breeding range of barred owls has expanded to include the Canadian provinces of Saskatchewan, Alberta, and British Columbia, with records in the Alaskan panhandle, Canada's Northwest Territories, and Washington State, Oregon, and California (Livezey 2009a).

The barred owl invasion from eastern to western North America appears to have followed one of two hypothesized routes. The first includes leapfrogging across the northern Great Plains via forested riparian corridors and forested areas created by human settlement of the once treeless landscape (Livezey 2009b). The second involves the documented northward movement of the species correlated with anthropogenic climate change, which allowed the owls to populate and move westward through Canadian forests north of the Great Plains

Figure 2. Current distribution and density of barred owls (*Strix varia*) in North America. The underlying barred owl distribution map was taken from The Birds of the World (https://birdsoftheworld.org/bow/species/brdowl/cur/distribution#hist) and is based on eBird data. The historical range of barred owls aligns with areas displayed within the eastern portion of the map. The invasive range of barred owls (displayed on the map in western sections of Canada and the US) was derived from substantial numbers of owls observed within these areas in the past 80–120 years. The blue outline delineates the range of the northern spotted owl (*Strix occidentalis caurina*), while green outlines delineate the range of the California spotted owl (*Strix occidentalis occidentalis*). This figure uses data and maps generated from eBird at the Cornell Laboratory of Ornithology, www.ebird.org. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the Cornell Laboratory of Ornithology. Image credit (barred owl): Blair Dudeck/Cornell University Macaulay Library (https://macaulaylibrary.org/asset/281379091).

(Monahan and Hijmans 2007). Regardless of which route contributed more, human alteration of climate and local habitat likely played pivotal roles in facilitating the westward movement of barred owls as well as other avian species from eastern North America.

Impact of native invasive barred owls on spotted owls

Barred owls first encountered northern spotted owls (*Strix occidentalis caurina*) in British Columbia and Washington State in the 1960s, followed by California spotted owls (*Strix occidentalis occidentalis*) in the Sierra Nevada, California, in the 2010s (Taylor and Forsman 1976; Hofstadter *et al.* 2022). The northern spotted owl is currently federally listed as threatened under the US Endangered Species Act, and the California spotted owl has recently been proposed for listing. The 1990 listing decision for the northern spotted owl was predicated on loss of habitat through timber harvest in older forests. Since the time of listing, the threat posed by barred owls has been increasingly well documented (Wiens *et al.* 2014). Although habitat loss and degradation continue to imperil spotted owls, interference by and exploitative competition with barred owls are now recognized as the primary threats to northern spotted owl populations—even in areas where habitat is well preserved (Franklin *et al.* 2021; Gutiérrez *et al.* 2007; USFWS 2013; Wiens *et al.* 2021). As barred owl populations continue to spread within the Pacific Northwest, populations of northern spotted owls have declined to the point of near extirpation, especially in the northern regions, where barred owls have been present for a longer period of time (Franklin *et al.* 2021).

As a generalist predator that can reach high densities, barred owls likely have a broad range of negative effects on western forest ecosystems via predation on avian, mammalian, and amphibian fauna that also serve as important prey for other native predators beyond spotted owls (Holm *et al.* 2016). While spotted owls in the Pacific Northwest primarily prey on small mammals, predominantly flying squirrels (*Glaucomys* spp), woodrats (*Neotoma* spp), and deer mice (*Peromyscus* spp) (Forsman *et al.* 2004), barred owls in the Pacific Northwest prey on a wider variety of taxa, including a broad spectrum of mammals, birds, reptiles, amphibians, and insects (Wiens *et al.* 2014; Kryshak *et al.* 2022; Baumbusch 2023). In addition, barred owl abundance has been correlated with declines in western screech-owl (*Megascops kennicottii*) populations on Washington State's Bainbridge Island (Acker 2012). Thus, the more generalist diet of invasive barred owls raises concerns about how this species may impact diverse prey populations that have not previously been exposed to this predator.

The justification for lethal control

As the negative impacts of barred owls on northern spotted owls became increasingly evident in the mid-2000s, scientists and resource managers considered a variety of

research and management options for understanding and mitigating those impacts (reviewed by Buchanan *et al.* [2007]). These same options are generally applicable to any invasive species. In addition to taking no action, management options considered by Buchanan *et al.* (2007) included: (1) performing observational ecological studies to identify the causes and consequences of competitive interactions between barred and spotted owls; (2) conducting barred owl removal experiments to establish whether barred owls were the ultimate cause of population declines in spotted owls; (3) managing habitats, assuming that particular habitat conditions favored spotted owls over barred owls and thereby provided refugia from barred owls; (4) diversionary feeding of barred owls to reduce barred owl competition with and predation on spotted owls and other wildlife; and (5) disrupting barred owl reproduction through a variety of methods. Of these options, ecological studies (option 1) and removal experiments (option 2) were considered by scientists and management agencies to be key steps toward understanding whether barred owls were the ultimate factor in causing declines in spotted owl populations and whether removing barred owls could improve population viability of spotted owls (Buchanan *et al.* 2007; USFWS 2013). Although translocation was considered as an alternative to lethal control, there was nowhere to relocate the thousands of barred owls requiring removal. In addition, the other options were deemed currently unfeasible for eliminating the barred owl threat. For example, disrupting barred owl reproduction does not directly address the impacts of thousands of adult barred owls on spotted owls. Moreover, barred owls are generally more difficult to capture and treat using untested chemical sterilization methods, or laparoscopic sterilization, which requires expertise and cost far beyond what is required for lethal removals (Klug *et al.* 2023; Massei 2023). For these and other reasons, alternative methods are not yet available or feasible at the scale needed to counter the threat of barred owls (USFWS 2013).

In 2013, the US Fish and Wildlife Service (USFWS) initiated a large-scale, multiyear, before–after control–impact (BACI) experimental removal study utilizing lethal control of barred owls in multiple study areas while simultaneously monitoring demographic trends in northern spotted owls (Wiens *et al.* 2021). Once released from competition with barred owls, spotted owl populations in these study areas stabilized 3–6 years after barred owl removal. Removal of barred owls also strongly increased survival of sympatric northern spotted owls as evidenced by an average change in apparent survival ranging from 0.04 to 0.17, with a weaker, positive effect on spotted owl recruitment (Wiens *et al.* 2021). Ultimately, the mean annual rate of population change for spotted owls stabilized to declines of 0.2% in areas with removals as compared to declines of 12.1% in areas without removals (Wiens *et al.* 2021). This field experiment established the cause-and-effect relationship between barred owl presence and population declines of spotted owls as well as highlighted the feasibility and efficacy of using lethal control to reduce the immediate threat of barred owls to spotted owls. The work also prototyped methods and demonstrated that removal using shotguns could be done quickly and humanely with a single lethal shot. Thus, lethal control of barred owls is currently the only feasible, humane, and experimentally validated means of effectively and rapidly reducing the threat posed to spotted owls by encroaching populations of barred owls.

Ethical considerations of management by lethal removal

Wildlife conservation frequently involves having to make difficult choices, one of which is the use of lethal control. In the case of barred owl effects on spotted owls, the USFWS formed a 40-member stakeholder group to evaluate the ethics of a barred owl removal experiment (Lynn 2018). This group concluded that (1) compassion was crucial to management of barred owls in the West; (2) society also had moral responsibility to assist the spotted owl; (3) lethal control experiments were justified but should minimize harm and suffering; and (4) viable non-lethal alternatives should be developed, given that few, if any, are currently available.

Lethal control is a tool that is often used to manage wildlife populations, even when native species pose a threat to threatened or endangered species. However, lethal control is less societally acceptable when charismatic fauna, such as barred owls, are involved (Lute and Attari 2017). Moreover, even within the conservation community, there is disagreement about whether lethal control is ethical in managing wildlife populations. Opponents of lethal control espouse "compassionate conservation", which supports conservation goals but retains a commitment to the welfare of wildlife individuals; these opponents maintain that the costs to solve conservation problems, even those involving invasive species, through harsh measures are too high (Coghlan and Cardilini 2022). In contrast, proponents of lethal control argue that compassionate conservation is too simplistic and fails to acknowledge the complexity of ecological or human cultural systems that sometimes require the use of lethal control to effectively manage invasive wildlife (Coghlan and Cardilini 2022).

In the case of barred owls in the West, spotted owl populations are continuing to decline at a precipitous rate while barred owl populations continue to expand and increase (Franklin *et al.* 2021). The best available data suggest that the choice of whether to use lethal control as a management tool represents a choice between the increasing mortality and loss of spotted owls versus the death of some barred owl individuals from lethal control. Although it is not inevitable that lethal removal will be used to help conserve spotted owls in the future, it is important to clearly understand that

there is a trade-off in accepting inaction, further delays, or less effective management choices. We believe that a decision to conduct strategic barred owl control may be critical for the persistence of northern spotted owls and should additionally provide broader ecosystem protection. As such, lethal removal of barred owls in western North America has the potential to maintain spotted owl populations but will not affect native barred owl populations in eastern North America, thus conserving both species within their respective native ranges.

While the decision to kill individuals of one species to protect another is a difficult one that we do not take lightly, we believe that the choice to lethally remove barred owls, if done in a humane manner, balances ethical considerations with maintaining ecological integrity (Lynn 2018). Field protocols for lethal removal of barred owls, which involve the use of shotguns in an efficient, humane, and cost-effective manner (Diller *et al.* 2014; Wiens *et al.* 2021), are well established and have been successfully utilized at multiple scales (Diller *et al.* 2016; Wiens *et al.* 2021; Hofstadter *et al.* 2022). For example, 2485 barred owls were eliminated over periods of 3–6 years at five different study areas (Wiens *et al.* 2021) and, in studies reporting removal effectiveness, 100% of 73 individual barred owls (Diller *et al.* 2014) and 97.4% of 883 individual barred owls (Wiens *et al.* 2018) were killed with a single shot. In all cases, lethal removals were conducted under strict protocols through state and federal permits, which required rigorous training for personnel involved in lethal removals. We also suggest that the future development of non-lethal alternatives, such as reproductive control, is paramount to either supplement or replace lethal control, and the development of novel approaches is critical for shaping future management practices. However, the immediate solution to rapidly declining spotted owl populations is the strategic removal of barred owls from the system, which we believe is currently the best ethical and ecological choice.

Removal-centered management

Multiple actions can be applied to managing the invasion of barred owls into western North America, which incidentally are also applicable to other situations where invasive species negatively impact ecosystems. First, swift and efficient management intervention in the form of lethal control can often effectively curb the near-term existential threat that invasive species pose to local fauna (Butchart *et al.* 2006; Lavers *et al.* 2010). For example, lethal removal of feral pigs and goats resulted in an order of magnitude increase in densities of native Galápagos rails (*Laterallus spilonotus*; Donlan *et al.* 2007).

Second, once the threat is recognized, immediate action is needed to prevent the spread of invasive species into new areas before they become entrenched in the system. Barred owl populations grow rapidly in many areas, which allows them to achieve high densities that later require additional management actions and expense. Delays and inaction only increase the effort needed to control or eliminate the invasive species. Thus, immediate action can reduce the overall cost of a barred owl management program and is consistent with the ethic of lethally removing as few individuals as possible to achieve conservation goals. This strategy was successfully employed in the Sierra Nevada of California, where only 76 invasive barred owls had to be removed over 3 years for the breeding population in the area to be effectively eradicated (Hofstadter *et al.* 2022), with minimal subsequent effort needed. Likewise, in the southern extent of the northern spotted owl range in Marin County, California, fewer than five barred owls are found and removed per year.

Finally, successfully managing native invasive species for the benefit of ecological resources requires a variety of approaches and prioritization. The ratio of barred owls to spotted owls is highly variable across the landscape, and therefore strategies will need to vary spatially. Along the coasts of Oregon and northern California, barred owl densities are high and increasing annually, but spotted owls remain in the region and populations could rebound relatively quickly after the removal of the invader (Diller *et al.* 2016; Wiens *et al.* 2021). In this instance, barred owl removal should have an immediate and substantial impact on spotted owl recovery (Franklin *et al.* 2021). In areas such as Marin County and the Sierra Nevada in California, because barred owls remain rare and are not yet limiting spotted owls, modest numbers of annual removals can effectively prevent barred owl populations from becoming established. Where spotted owls still exist, barred owl control in strategic areas could allow spotted owls to persist indefinitely until other solutions become available. However, in Washington State and northern Oregon, barred owl densities can be extremely high, with few or no spotted owls remaining in the landscape. In these areas, even with barred owl removals, spotted owls may require additional management strategies to recover, such as translocation or captive breeding programs.

Currently, barred owl removals are limited to research studies that are finite and have limited spatial scales relative to western forested landscapes. While these studies have demonstrated how lethal control can reduce local barred owl populations and increase spotted owl populations, they alone cannot accomplish the large-scale, substantial, and long-term reductions in barred owl populations needed to mitigate impacts to spotted owls and forest ecosystems. To address the large-scale, range-wide requirement to protect spotted owls, the USFWS developed a longer-term and more comprehensive barred owl management strategy that will include alternative measures for addressing the numbers of barred owls to be removed, and the temporal and spatial extents of removals (USFWS 2023a). However, this strategy is voluntary, has yet to be finalized, and may require multiple years of planning, review, and environmental compliance to reach implementation—during which time barred owl populations and their negative impacts will expand further.

The scope of potential barred owl management in the western US

Implementation of barred owl removal needs to occur at large spatial scales to promote spotted owl recovery; this requires a coordinated, range-wide effort to reduce the threat of barred owls to spotted owl populations. Ideally, strategies would be implemented within an adaptive management framework (eg Nichols *et al.* 2007) where monitoring of spotted owls and barred owls is conducted to continually assess program effectiveness and where changes to management, including termination thereof, are made if needed. Having such a program in place would also provide strong incentives to develop non-lethal management alternatives while maintaining viable spotted owl populations.

As mentioned above, the USFWS and partner agencies have developed a draft barred owl management strategy within the range of the spotted owl (USFWS 2023a). Maintaining viable populations of California spotted owls should be tractable given low barred owl densities within their range, which recent lethal removals have reduced to very low levels (Hofstadter *et al.* 2022); only 10–15 barred owl removals will be needed annually to ensure negligible effects on this subspecies (Hofstadter *et al.* 2022; Peery unpublished data). Similar efforts could also be implemented in Marin County, California, where barred owls are not yet resident.

By comparison, promoting viable populations of northern spotted owls elsewhere will be more challenging and require coordinated barred owl management spanning California, Oregon, and Washington State. The cost of intensive removal efforts in areas of high barred owl density may preclude "wall-to-wall" management across such a large region, where even areas such as individual national forests may be cost-prohibitive. Rather, effective outcomes could be efficiently achieved by prioritizing landscapes potentially containing at least 50 spotted owl pairs (~175–1150 km^2) for barred owl management. While these management landscapes would ideally be well-distributed across the range of the northern spotted owl, barred owl management in California and parts of Oregon is particularly urgent. Based on a pilot study in the Six Rivers National Forest in California, barred owl management within each of these landscapes would cost ~$150,000–$400,000 annually, depending on size and organizational cost structure, in the initial few years. Managing barred owls in ~30 landscapes across the range of the northern spotted owl, as proposed by the USFWS (USFWS 2023a), would thus require $4,500,000–$12,000,000 in funding annually during the initial stages. Costs, however, would be expected to decline, possibly substantially, after the first few years, once barred owl densities have been reduced to more manageable numbers.

Nevertheless, we may have reached the realm of "forever management" as dispersal by barred owls from unmanaged areas into management landscapes inevitably necessitates low-level removals in perpetuity, at least with current technology. Indeed, there should be no illusions regarding the substantial effort required for barred owl management, with the USFWS estimating that up to ~16,000 barred owls could be removed per year (at maximum implementation) under the preferred alternative of the management strategy (USFWS 2023b). Moreover, the reestablishment of northern spotted owls in areas from which they have been effectively extirpated (eg much of Washington State) will be slow and potentially require population augmentation efforts. Yet, with a well-designed prioritization strategy and adequate funding commitments, we expect that barred owl densities could be reduced to levels compatible with viable northern spotted owl populations in many areas in 5–10 years, potentially to the benefit of many other endangered species and entire ecological communities.

Conclusions

Decades of barred owl population growth with negligible intervening management have led to the current dire predicament for spotted owl populations and left managers with difficult choices. Similar delays with other native invasive species will result in similar predicaments and require proactive, costly, and ethically more challenging approaches to provide effective management strategies. The invasion of barred owls is among the first and best-documented examples of a native invasive vertebrate species having negative effects on forested systems outside their native range. There is strong scientific evidence that (1) invading barred owls have negative impacts on spotted owls and possibly other species, and (2) lethal removal of barred owls can result in rapid stabilization of spotted owl populations in the removal areas. As such, the relevant land and wildlife management agencies and decision makers have a responsibility to take proactive measures regarding barred owl removal to prevent the ultimate extinction of spotted owls and other sensitive forest species.

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Data Availability Statement

Data from eBird were used to generate Figure 1 using the following steps: on the eBird website, the species page for

blue jay (*Cyanocitta cristata*) was accessed under the "Explore Species" option (https://ebird.org/species/blujay); in the Range Map window, we accessed the Large Map and modified the "DATE:" field to Year Round and 10-year increments (eg 1950–1959, 1960–1969, and so on) and excluded "Not reported" data.

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