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# Not just a flash in the pan: short and long term impacts of fireworks on the environment

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## ABSTRACT

Fireworks are used globally, mostly for recreational purposes, despite overwhelming evidence that they negatively affect wildlife, domestic animals, and the environment. Fireworks cause short-term noise and light disturbance, causing distress in domestic animals that may be managed before or after a fireworks event, but impacts to wildlife can be on a much larger scale. The annual timing of some large-scale fireworks events coincides with migratory or reproductive behaviour of wildlife, and thus may have adverse long-term population effects on them. Fireworks residues also contribute significantly to chemical pollution of soil, water, and air, which has implication for human as well as animal health. Modern technological alternatives to traditional fireworks – both 'eco-friendly' fireworks, and reusable drone and laser-based lightshows – provide safer, 'greener' alternatives that also present a sustainable way forward for maintaining cultural traditions without perpetuating their adverse impacts.

**Keywords:** bioaccumulation, fireworks, heavy metals, light pollution, noise pollution, perchlorate, pollution, wildlife disturbance.

## Introduction

Firework displays are an anthropogenic disturbance that produces both immediate light and noise disturbance and lingering pollution. Aerial fireworks have typical burst heights between 100 and 200 m and can reach 270 m, with burst diameters of 100–150 m, lasting 1–6 s (Zrnić *et al.* 2020). Noise pollution can exceed 85 dB – the level at which harm can occur to human eardrums (Ambade and Ghosh 2013; Wallace 2022). Fireworks are usually associated with particular events and festivals and hence represent relatively brief but intense bursts of noise, light and particulate pollution at certain times of year. Although fireworks can be considered stochastic disturbance events analogous to natural events such as thunderstorms, there has long been recognition that firework displays are highly disturbing to human companion animals (e.g. Gates *et al.* 2019), and there is growing recognition in some communities that firework displays also causes disturbance to wildlife. In ecologically minded communities, e.g. in the Galápagos Islands (Anon 2018), this awareness has sometimes resulted in the banning of fireworks displays.

Animals, both wild and domesticated, that live within or near urban development are exposed to increased human disturbance, noise and light levels, chemical pollution, novel foods, and novel habitat features. In response to anthropogenic influences, some wild animals vacate such areas (urban avoiders) while others benefit to a certain extent, for example from increased anthropogenic food sources, refuge from predators, or novel sources of prey (urban adapters). Some species are obligate synanthropists, living only in urban areas (urban exploiters) (McKinney 2006; Bateman and Fleming 2012; Tryjanowski *et al.* 2020). There is some evidence that urban adapter or urban exploiter organisms can adapt to noise and light (Lowry *et al.* 2013; Fleming and Bateman 2018), and can modulate their behaviour in reaction, e.g. becoming less reactive to loud noises (Lowry *et al.* 2011); however, noise can cause stress hormone increases even in urban animals (Ditchkoff *et al.* 2006; Shannon *et al.* 2016). There can also be other costs for urban animals: chicks of Western Bluebird (*Sialia mexicana*) in nests exposed to anthropogenic noise and light were both smaller and had poorer body condition than those in control nests (Ferraro *et al.* 2020), while Pinyon Mice (*Peromyscus truei*) trapped across a gradient of anthropogenic noise and light showed lower activity (trap success) in higher light zones and reduced body condition in noisier areas (Willems *et al.* 2021).

Urban wildlife can often have higher tissue levels of pollutants than ex-urban conspecifics, e.g. lead in urban House Sparrows (*Passer domesticus*) (Chandler *et al.* 2004), which may then pose a threat, via bioaccumulation, to raptors preying on sparrows. Anticoagulant rodenticides can bioaccumulate in urban reptiles, with potential consequences for their predators (Lettoof *et al.* 2020).

Here, we present a short review and commentary on what is known about the effects of firework displays on wildlife and the environment, with the aims of elucidating the extent of disturbance and damage they may be causing, and of making some suggestions for how these impacts could be reduced.

## Noise and light

That fireworks' noise and light is disturbing and distressing to animals is well known to most pet owners. Noise phobia in dogs is a well-documented response to fireworks (e.g. Dale *et al.* 2010). In a survey from New Zealand, owners reported that 74.4% of companion animals, from horses to small mammals, showed fear responses to fireworks (Gates *et al.* 2019). Horse owners reported increased running in response to fireworks, often associated with fence-breaking and injury (Gronqvist *et al.* 2016). Observation of several mammal and bird species in a German zoo before, during and after 6–8 min long firework displays over two evenings showed increased nervousness, movement, withdrawal to indoor areas (Rodewald *et al.* 2014). Associative learning can induce fear responses to the smells associated with fireworks or even the fall of darkness (Mills 2005).

That fireworks and firecrackers work in frightening animals is shown in their use as hazing tools in both urban and ex-urban areas against birds in crops and at aquaculture sites (e.g. Zajanc 1962; Barras and Godwin 2005; de Carvalho *et al.* 2019), macaques (*Macaca fuscata*) in Japanese villages (Honda *et al.* 2019), and coyotes (*Canis latrans*) in Californian towns (Baker 2007).

It is not surprising then that firework events – occurring intermittently and consisting of unpredictable bursts of light and noise – appear to have negative effects on many species of wildlife. Data from 3 years of weather radar in the Netherlands showed that thousands of birds take flight shortly after fireworks are lit at midnight on New Year's Eve (Shamoun-Baranes *et al.* 2011). Hundreds of thousands of birds are disturbed in this way, flushing them from wetlands where they rest. Similar examples are global: in Poland, urban Eurasian Magpies (*Pica pica*) roost together in larger communal roosts than in ex-urban areas, but roost size sharply and suddenly declines on New Year's Eve due to fireworks (Karolewski *et al.* 2014). On Lake Zurich in Switzerland, New Year fireworks can cause a 26–35% drop in swan, goose, and duck numbers overnight, the numbers recovering over 3–10 days (Weggler 2015). At Lake Constance in Germany, a firework display on the 13 September 2010 caused extreme flight reactions in multiple waterbird species, causing over 4000 waterbirds to flee from the area almost immediately. Many waterbird species are in wing-moult at this time of year, so it is significant that even temporarily flightless birds left the area and stayed absent for over 2 days. As Lake Constance is a recognised refuge for moulting waterbirds, this fireworks display has subsequently been banned (Werner 2015). At Beebe, Arkansas, USA, two powerful displays of New Year fireworks in 2011 and 2012 caused the deaths of thousands of Red-winged Blackbirds (*Agelaius phoeniceus*) that were disturbed from winter roosts at night and, in their flight, collided with each other (Chilson *et al.* 2012).

A thorough review of solicited observations and unpublished data on birds and fireworks gathered by Stickroth (2015; primarily from Germany) indicated that most observations supported a negative response by birds to fireworks: Greylag Goose (*Anser anser*), White Stork (*Ciconia ciconia*) and Common Crane (*Grus grus*) consistently reacted the most strongly among species across reports. Although flashing light from fireworks caused reactions at close range, the greatest responses were to the associated noises. Flight was common in response to noises, even in young storks, which jumped out of nests despite being unable to fly. Birds in open country and birds in colonies reacted more strongly than did birds in woodland, which were hypothesised to feel safer under cover. Captive birds that are unable to flee have shown strong physiological stress responses to fireworks: a Griffon Vulture's (*Gyps fulvus*) heart rate went from 50 to 170 bpm when exposed to firework disturbance (Stickroth 2015).

The ecological effects from firework noise can be long term and influence breeding success: in Valencia, Spain, several festivals that include fireworks occur between April and May, and breeding success of House Sparrows (*Passer domesticus*), as measured by ratio of adults to juveniles, was lower in towns hosting festivals than in control towns without festivals. Notably, cancellations of the festivals in 2020 due to COVID-19 resulted in the breeding success of sparrows in both groups of towns becoming equal (Bernat-Ponce *et al.* 2021).

Depending on the time of year, fireworks can influence various aspects of bird behaviour. New Year fireworks in northern hemisphere winters are more likely to influence congregations of roosting birds, which in the summer months are dispersed around their breeding areas. However, Independence Day (4th July) fireworks are often banned in areas where endangered birds, particularly colonial ones, are breeding, e.g. Western Snowy Plovers (*Charadrius alexandrinus nivosus*) in Washington State, USA (Pearson *et al.* 2008). July firework displays have been implicated in the decline of Brandt's Cormorant (*Phalacrocorax penicillatus*, now in genus *Urile*) colonies (LeValley 2010) in California, USA. Diwali, a festival celebrated with fireworks in October and November across India, occurs during winter bird migration across much of the country, though reports of impact to migrants are not available.

Although most studies on the effects of fireworks, outside of domestic and zoo animals, have been centred on birds, observations have been carried out on California Sea Lions (*Zalophus californianus*), Harbour Seals (*Phoca vitulina*) and Sea Otters (*Enhydra lutris*) in Monterey Bay, California, USA, during and after 4th of July fireworks. Both sea lions and seals, which had been hauled out and resting, took to the water in response to the fireworks but had returned by the next day. Otters were seen in the bay shortly after the fireworks ended and it was assumed that the display only caused a short disruption in behaviour (Thorson and Berg 2007). South American Sea Lions (*Otaria flavescens*) in Chile, exposed to New Year's fireworks when onshore during their breeding season, stopped vocalising, showed alert behaviour, and many left the colony during the display and took over 24 h to return (Pedreros *et al.* 2016). Although the short-term impacts appear similar in these two cases, disruption during breeding is likely to have more significant long-term impact on a species.

## Pollution

Fireworks cause pollution, releasing sulfur dioxide, carbon dioxide, carbon monoxide, suspended particles, aluminium, manganese etc., in a black smoke of potassium nitrate, charcoal and sulfur (Sijimol and Mohan 2014). The particulate matter released has a profound and immediate negative effect on air quality, but declines rapidly over the next 24 h (Singh *et al.* 2019). After firework displays, particles released can be five times higher than background levels (Cao *et al.* 2018). In New Zealand, a steep rise in particulate matter has been reported after fireworks, with much of it coming from small, hand-held sparklers (Rindelaub *et al.* 2021). Dangi and Bhise (2020) reported multiple respiratory and allergic responses in residents at a site after Diwali celebration. The toxicity of the particulate matter released is high – tests with mice and human cell cultures indicate high inflammatory responses and adverse effects on cells and lung tissue (Hickey *et al.* 2020).

Of particular concern is the presence of the inorganic anion perchlorate (as potassium perchlorate and ammonium perchlorate), which contributes to the explosions and light associated with fireworks (Wu *et al.* 2011). Perchlorates are water soluble and stable, leaching into water bodies and being taken up by plants after release, and making their way into insects, mammals, amphibians and fishes (reviewed in Sijimol and Mohan 2014). Perchlorate is a major health concern as it inhibits thyroid function in amphibians, reptiles and mammals, decreasing thyroid hormone output – it also has a role in causing reproductive, neurodevelopmental, developmental, immunotoxic, and carcinogenic issues (Utley 2002). Many publications indicate the widespread presence of perchlorate in water, crop plants, milk, and fish (Kirk *et al.* 2003; Dyke *et al.* 2007; Park *et al.* 2007; Isobe *et al.* 2013; Calderón *et al.* 2020; Kumar 2020). While perchlorates do not bioaccumulate and there is evidence that they can sometimes rapidly be expelled from the body (Park *et al.* 2007), they can still make their way into the food chain and to humans (Kirk *et al.* 2003; Sijimol and Mohan 2014; Calderón *et al.* 2020).

Fireworks also deposit a range of heavy metals into soil, air and water, sometimes in large amounts (Moreno *et al.* 2010; Rindelaub *et al.* 2021). These metals from fireworks can be inhalable and therefore an immediate health risk to people (Moreno *et al.* 2007; Fu *et al.* 2021), but they can also bioaccumulate – e.g. in soil bacteria (Rajeshkumar *et al.* 2012), moss (Świsłowski *et al.* 2021), fish and mammals (Baby *et al.* 2010). Bioaccumulation of heavy metals in food can then pass to humans, but can also directly affect the health of other taxa, e.g. Marsh Frogs (*Pelophylax ridibundus*) with high levels of heavy metals and metalloids from a polluted wetland in Bulgaria were anaemic and demonstrated weakened immunity (Zhelev *et al.* 2020). Metals and metalloids from pollution in urban lakes in Perth, Australia, are implicated in low body condition of Tiger Snakes (*Notechis scutatus*) in the worst affected wetlands: such metals bioaccumulate in the snakes, making them available to snake predators (Lettoof *et al.* 2021).

## Suggestions

The overwhelming evidence points to fireworks being environmentally highly damaging, having immediate disturbance effects on many animals through light and particularly noise – effects that can be long lasting. They also produce significant pulses of highly pollutant material, which can have both immediate and long-term effects on the environment and translate into health issues for wildlife and for humans (see Fig. 1).

Despite this – and studies indicating the negative effects of fireworks now go back decades – such displays continue to be part of many celebrations globally. Indeed, such displays are arguably increasing in number and intensity: Indian researchers in particular have been at the forefront

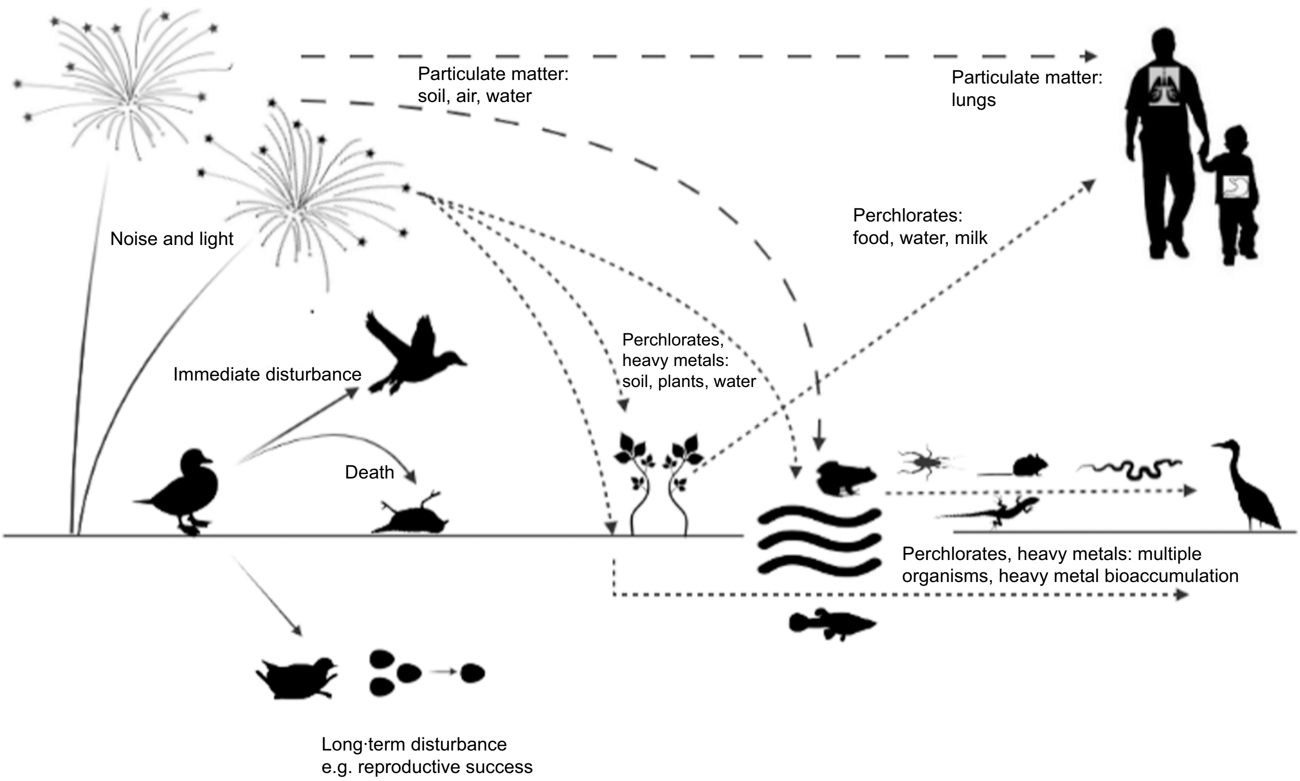


**Fig. 1.** Conceptual diagram of the effects of fireworks on the environment, from immediate disturbance of birds and other animals, through to rapid pollution of air quality by particulate matter, and deposition of perchlorates and heavy metals into soil and water where they can transfer to humans or bioaccumulate in food chains.

of highlighting the polluting effects of extensive firework displays associated with religious festivals (e.g. Yerramsetti *et al.* 2013; Ambade 2018; Prabhu *et al.* 2019; Singh 2020; Ravindra *et al.* 2022). A UK government report (Office for Product Safety & Standards 2021) indicated that 61% of people surveyed saw fireworks as enjoyable, and 44% saw fireworks as an important part of British culture and did not wish to see bans of displays.

As bans on fireworks are unpopular, what mitigation of the effect of fireworks on the environment can we propose? For pets, in the face of light and noise trauma, there is at least some evidence that horses can be gradually habituated to flashes of light (https://www.bhs.org.uk/go-riding/riding-out-hacking/common-incidents/fireworks/). Otherwise there is little that can be done, particularly as it appears to be noise rather that light that is disturbing (Stickroth 2015). For wild animals, the extensive potential immediate damage to multiple taxa, particularly birds, from firework displays, both short and long term, can only be mitigated by outright bans or by stringent management of timing, intensity and duration of displays attuned to behavioural ecology of affected species (which required both awareness of and availability of data for such species). At the very least, local bans (e.g. Pearson *et al.* 2008; Werner 2015) and consideration of which taxa are likely to be most affected at the time of year of the displays (summer breeding or winter migration) should be implemented.

'Eco-friendly' fireworks, which do not use perchlorate and have lower levels of heavy metals, do exist (Fan *et al.* 2021); the problem lies in their higher cost of manufacturing (Palaneeswari and Muthulakshmi 2012). The future of 'firework' displays may lie in the use of drones or unmanned aerial vehicles. Drones and visible-wavelength lasers for light shows have the benefit of being reusable, have no emissions, and are quiet (Daukantas 2010; Zerlenga *et al.* 2021). Drones come with their own issues for wildlife, however, usually flying at low altitudes where there are most likely to come into contact with wildlife; a review indicated that many taxa react negatively to the presence of a drone (Rebolo-Ifrán *et al.* 2019). Even so, drone light shows are less likely to disturb animals, wild or domestic, with noise, nor do they deposit large amounts of pollutants.

There is a growing recognition that events can be managed in a sustainable way, making use of 'green' practices (Ramely *et al.* 2022), reducing use of plastics, transport etc. Fireworks do not tend to be specifically addressed in such practices: in the face of their undoubted negative environmental effects, this needs to change.

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