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INVASION NOTE

Invasive species denialism revisited: response to Sagoff

Anthony Ricciardi · Rachael Ryan

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Science denialism is the use of rhetorical tactics and the systematic rejection of empirical evidence to cast doubt on the consensus of a field of science (Diethelm and McKee 2009). It aims to give the appearance of legitimate debate where there is none. For many years, denialism has pervaded public debates on climate change policy, the teaching of evolution in the classroom, the benefits of vaccination, and the health effects of tobacco (Oreskes and Conway 2010). Typically expressed in forums where it avoids expert peer review, denialism is characterised by, inter alia, (1) reliance on rhetorical or emotional arguments rather than verifiable facts; (2) repetition of claims that have been debunked by evidence, without acknowledging factual rebuttals; (3) selective 'cherry-picking' and 'quote-mining' of published studies; and (4) undermining the credibility of experts through unsubstantiated accusations of bias, dishonesty, or conspiracy (Hoofnagle and Hoofnagle 2007; Diethelm and McKee 2009; Weart 2011; Hansson 2017, 2018).

As pointed out recently (Russell and Blackburn 2017; Ricciardi and Ryan 2018), these tactics are increasingly employed in critiques of invasion ecology, including some in which contrarians have dismissed the field as a "pseudoscience", "bad ecology", and "green xenophobia" (Theodoropoulos 2003; Pearce 2018). However, in the scientific realm, rhetoric cannot discount an entire body of systematic observation and experimental research that has yielded valuable insights into fundamental and applied ecological questions—such as what forces shape ecological communities and food webs, why island biota are vulnerable to extinction, or how ecosystem functions can be altered by changes to species composition, to name a few. Although scientific debate is normal, healthy, and necessary for a thriving discipline, many criticisms repeatedly leveled at the field do not withstand scrutiny (Richardson and Ricciardi 2013). Scientific evidence supports the consensus that non-native species introductions carry significant ecological risks, that they are a major contributing cause of population declines and extinctions, and that they can substantively alter or disrupt ecosystem functions and services upon which society depends (Simberloff et al. 2013). At the same time, ecologists recognize that many invasions are (at present) innocuous; indeed, developing a predictive understanding of the differences between disruptive and innocuous invasions is a major research goal for the field.

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A. Ricciardi (✉) · R. Ryan
Redpath Museum, McGill University, 859 Sherbrooke Street West, Montreal, QC H3A OC4, Canada
e-mail: tony.ricciardi@mcgill.ca

Denying denialism

Nevertheless, the growth of invasion ecology has attracted a rising number of attacks from contrarians, primarily in non-scientific journals and the popular press. We demonstrated this by quantifying the frequency of articles that exhibited at least some of the characteristics mentioned above and we listed the articles in an appendix to make them accessible to readers (Ricciardi and Ryan 2018, Supplementary Material). Sagoff (2018) objected to his articles being identified as examples of science denialism, asserting that the mere act of citing them as such is an ad hominem attack comparable to being labeled a Holocaust denier. A similar complaint has been voiced by some people who deny climate science (e.g. Bradley 2017; but see Dykstra 2017). However, Oxford Dictionaries define "denier" exclusively as "*A person who denies something, especially someone who refuses to admit the truth of a concept or proposition that is supported by the majority of scientific or historical evidence*—[*e.g.*] '*a prominent denier of global warming*', '*a climate change denier*'" (en.oxforddictionaries.com; accessed 13 April 2018). To describe these contrarians as skeptics would be inaccurate, as true skeptics should be willing to accept evidence and not deny where it leads, whereas science deniers aim to cast doubt on expert consensus (Weart 2011). 'Denial' is thus recognized by scientists, science communicators, and journalists as an appropriate term for describing unwarranted doubt and outright dismissal of facts by those who avoid normal scientific discourse (Anderegg et al. 2010; Oreskes and Conway 2010; Liu 2012; National Centre for Science Education 2018). Apart from the rejection of fact-based consensus, there is no logical or moral connection between the Holocaust and science denial, and we have never suggested otherwise. Nor have we suggested that contrarians who deny invasion ecology necessarily share the same beliefs as climate change (or other) denialists, though they may adopt similar tactics. The examples we cited (Ricciardi and Ryan 2018) indicate that the motivations behind invasive species denialism are diverse, involving actors with disparate ideologies (e.g. anti-pesticide activists, anti-regulatory ideologues, postmodernist philosophers and other groups who distrust scientific institutions). Sagoff might have hinted at his own motives by bemoaning government spending on combatting invasions (Sagoff 2011), but we made no attempt to rationalize his contrarianism; in fact, we did not discuss his opinions at all. Here, in response to his comment (Sagoff 2018) we explain in detail why several of his articles are correctly identified as invasive species denialism.

Repetition of debunked claims and misrepresentation of findings

A habitual contrarian, Sagoff has repeated a series of debunked and unsupported claims over two decades in his critiques of invasion ecology. These include ad hominem attempts to malign experts by insinuating that they are xenophobes (Sagoff 1999, 2000, 2007)—a malicious characterization commonly promoted by contrarians (e.g. Theodoropoulos 2003; Winograd 2013; Thompson 2014; Pearce 2018) and which has been deconstructed by Simberloff (2003). Sagoff (1999) claimed that "Those who seek funds to exclude or eradicate non-native species often attribute to them the same disreputable qualities that xenophobes have attributed to immigrant groups" including high fecundity, aggressiveness, and tolerance for degraded conditions (Sagoff 1999, 2000). He failed to recognize that these traits are derived from experimental and statistical studies that have shown them to be important predictors of invasion success in animals (e.g. Weis 2010; Capellini et al. 2015; Michelangeli et al. 2017) and that such studies have also identified larger brain size as a predictive trait of successful invaders (Sol et al. 2005, 2008; Amiel et al. 2011)—contrary to both Sagoff's fanciful narrative of immigrant denigration and his assertion that there are no intrinsic differences between native and non-native species. Neither Sagoff nor anyone else has presented evidence that scientists who study invasive species are more likely to be xenophobic than other scholars (even philosophers). This accusation is a merely a tactic for impugning the credibility of experts and it is consistent with the conflict-seeking attitude of science denialists, who often use fierce personal attacks to fabricate controversies (Hansson 2017, 2018).

Some ecologists (Simberloff and Strong 2000; Simberloff 2005) have pointed out Sagoff's selective and often incorrect use of the scientific literature whenever he argues that there is insufficient proof of impact to warrant action against invasions. He has long denied that non-native species play a major role in extinction, despite substantive evidence to the contrary (e.g. Bell et al. 2016, and see below). In 2000, he claimed "few—if any" of the recorded extinctions of native animals and plants in the continental United States can be attributed to invasions (Sagoff 2000); but even at that time, 27 species and 24 subspecies of North American freshwater fishes were known to be extinct and that non-native species were implicated by scientists as a contributing cause in about 68% of documented cases (Miller et al. 1989). In subsequent years, a series of widely cited studies added evidence that invasions have contributed to substantial losses of birds, mammals, fishes, amphibians and reptiles, globally (Clavero and García-Berthou 2005; Clavero et al. 2009; Bellard et al. 2016; Doherty et al. 2016); as far as we have seen, Sagoff has never acknowledged any of these studies. In his later articles, Sagoff (2005, 2018) emphasized the lack of recorded extinctions directly associated with non-native plants. In his reply to us, Sagoff (2018) quoted Russell et al. (2017) for stating "there are no documented examples of either 'in the wild'… or global extinctions… attributable solely to plant invasions". Russell et al. (2017) did not make this claim; the quote was from Downey and Richardson (2016) and, furthermore, was taken out of context; the full statement was as follows: "*Although there are no documented examples of either 'in the wild' (Threshold 5) or global extinctions (Threshold 6) of native plants that are attributable solely to plant invasions, there is evidence that native plants have crossed or breached other thresholds along the extinction trajectory due to the impacts associated with plant invasions*." Downey and Richardson (2016) reviewed published studies demonstrating that plant invasions push native plants along an extinction trajectory across thresholds defined by population decline and local population extinction, respectively, which can lead toward extinction in the wild and finally global extinction. In addition, Downey and Richardson (2016) discussed factors that may mask where natives occur along the trajectory, most notably the dearth of studies that have examined the extent of the threat posed by particular non-native plants to native plants. Sagoff (2018) also quoted Powell et al. (2011) that "plant invaders rarely cause regional extirpations or global extinctions, causing some to suggest that invasive species' influence on native biodiversity may not be so dire"; however, Sagoff neglected to mention that this statement was not a conclusion but rather a premise to be tested, in which the authors also noted that "some studies have shown large declines in biodiversity in areas that are heavily invaded by introduced plants" (Powell et al. 2011, p. 539) and they cited evidence of population declines and local extinctions owing to plant invasions. Continuing this series of selective quotations and misleading omissions, Sagoff (2018) cited Stohlgren and Rejmánek (2014) for mentioning "the absence of empirical evidence of continuing plant invasions causing extinctions", while ignoring the authors' conclusion that the relatively short times since invasion in many regions of the world are insufficient to observe the full impact of plant invasions on native species. In fact, Stohgren and Rejmanek (2014, p. 4) specified "*while we cannot assume that* [*population*] *extirpation leads to extinction, we argue that targeted invasive species control efforts and properly designed monitoring of native biodiversity at large spatial scales are essential to save native species*". There is indeed a growing consensus among ecologists that global extinction is an inappropriate metric for quantifying the impact of invasions, or any other stressor, on plant species (Gilbert and Levine 2013; Downey and Richardson 2016; Cronk 2016) because there are strong reasons to expect extensive lag times for plant extinctions that are on the order of centuries (Vellend et al. 2006; Cronk 2016).

Sagoff has also asserted that, on the whole, non-native species (including crops) "confer benefits that far outweigh their costs" (Sagoff 2000) but he has never adduced evidence of this. He has often used the zebra mussel, an iconic invader, to defend his argument that impacts of invasions are overblown. Pointing to the mussel's enhancement of benthic invertebrate communities and water clarity, Sagoff (1999) claimed that "the benefits of zebra mussels are ignored", a refrain echoed by Thompson (2014), Pearce (2015), and a recent magazine editorial (Anonymous 2017), among others. Obviously, the role of mussels in increasing the abundance and local diversity of benthic communities has been widely reported by scientists for many years (reviewed by Ward and Ricciardi 2007), otherwise Sagoff and other contrarians would not have been aware of it. Also widely reported since the early 1990s, but conspicuously ignored by Sagoff, is the rapid decline and local extinction of native mussel populations as a result of zebra mussel fouling throughout the Great Lakes and other invaded waterbodies (Ricciardi et al. 1995, 1996; Nalepa et al. 1996). One of Sagoff's oft-repeated tropes is that the zebra mussel "cleans lakes and rivers" by devouring algae resulting from agricultural runoff and municipalities' waste discharge (Sagoff 1999, 2000, 2005, 2007, 2011). Moreover, he claimed that biologists have "praised the work of the zebra mussel in clearing the water column" and credited it with "restoring native grasses and fishes", and thus the mussel should be hailed as a "saviour" (Sagoff 2005, 2007). Indeed, the growth of aquatic plants (including invasive species like Eurasian milfoil) has been positively affected by increased light transparency in some areas of the Great Lakes, and the diets of molluscivores have been enhanced by the mussel, yet we know of no example of a threatened species of plant or animal that has been restored in the Great Lakes because of the invasion. In fact, zebra and quagga mussels have shunted nutrients away from the open-water food web, causing severe reductions in prey fish communities to the detriment of the sport fishery (Roseman et al. 2014; Kao et al. 2016). Lake Michigan, in particular, has suffered steep declines in many prey fish populations upon which commercially important species depend, because the lake's productivity has been eroded by the enormous filtration capacity of the invasive mussels (Kao et al. 2016). Certainly, the lake is clearer than it has ever been, but not necessarily "cleaner". This massive increase in water clarity has stimulated excessive macroalgal growth on the lake bottom, and the decomposition of this material depletes dissolved oxygen and thus creates conditions for outbreaks of botulism bacteria. Such bacteria and the neurotoxin they produce is filtered by mussels and subsequently taken up by their predators—particularly an invasive fish (the round goby), which passes it to fish-eating waterfowl, thereby killing over a hundred thousand birds since 1999 (Yule et al. 2006; Essian et al. 2016). In addition, Lake Erie and other areas of the Great Lakes basin have become increasingly susceptible to toxic algal blooms since the 1990s (Obenour et al. 2014; Steffen et al. 2014), attributable in part to the activities of the invasive mussels. Selective filtration and alteration of nutrient cycles by the mussels promotes the proliferation of cyanobacteria (Vanderploeg et al. 2001; Bierman et al. 2005; Steffen et al. 2014; Tang et al. 2014). Colonies of *Microcystis* have been observed to be rejected from mussels as pseudofeces (in which the colonies remain viable) while other species of phytoplankton are digested (Steffen et al. 2014). *Microcystis* and other cyanobacteria produce neurotoxins and a hepatotoxin called microcystin, a potential tumour-promoter that accumulates in fish tissue. Microcystin concentrations in recreational and commercially important fish collected in Lake Erie and Lake Ontario were high enough in some specimens that, if eaten, they would cause a human consumer to exceed the daily intake limit recommended by the World Health Organization (Poste et al. 2011). The roles of dreissenid mussels in contributing to cyanobacterial blooms and avian botulism have been reported in scientific journals and mainstream media for more than a decade, and Sagoff would have become aware of them had he honestly sought to inform or validate his narrative.

After assuring his audience that he wrote his reply "not to attack invasion biology", Sagoff (2018) proceeded to denigrate the discipline as being based entirely on tautology and false distinctions between species. Here and elsewhere, Sagoff (2007, 2011) claimed that non-native species "behave no differently in general than native ones", contrary to the conclusions of researchers who have documented a broad suite of traits and behaviours that distinguish native and non-native species, both invasive and innocuous (e.g. Ordonez et al. 2010; Morrison and Hay 2011; Sol 2012; Alba et al. 2015; Seabloom et al. 2015). Ecologists have also documented functional differences between native and invaded ecosystems (e.g. Liao et al. 2008; Martin et al. 2014). Ecologists place importance on the biogeographic origins of a species because ample evidence indicates that evolutionary context matters (Salo et al. 2007; Paolucci et al. 2013; Buckley and Catford 2015; Seabloom et al. 2015; Rejmánek and Simberloff 2017). Non-native generalist predators, herbivores and ecosystem engineers that have no ecological analogue in a recipient community are more likely to disrupt food webs and native species populations, which are ecologically naïve to such invaders (e.g. Cox and Lima 2006; Russell et al. 2017).

Contrary to Sagoff's (2011) claim that similar proportions of native and non-native species cause harm, it has been shown that non-native consumers cause greater damage to native populations than do native consumers (Salo et al. 2007; Paolucci et al. 2013), non-native plants are 40 times more likely to spread and dominate communities than native plants (Simberloff et al. 2012), and non-native aquatic species in North America and Europe are several times more likely than native species to become pests (Hassan and Ricciardi 2014). A large body of research demonstrates that non-native species can disrupt ecosystem services, cause extinctions from local to global scales, and impose severe socioeconomic costs (Simberloff et al. 2013), which negates Sagoff's (2011) argument that in almost every case concern over non-native species is based on aesthetic, ethical, cultural or religious reasons, rather than scientific-informed ones.

In summary, each of Sagoff's articles we have cited has (1) made unsubstantiated assertions that contradict or ignore a growing body of empirical evidence, (2) dismissed scientific consensus with rhetoric rather than facts, (3) misrepresented scientific findings and statements by experts through cherry-picking and quote-mining, and (4) maligned experts with insinuations of bias. Collectively, these are the tactics of science denialism (Hoofnagle and Hoofnagle 2007; Diethelm and McKee 2009; Weart 2011; Hansson 2017, 2018). Our purpose in enumerating articles that exhibit these characteristics was to evaluate Russell and Blackburn's (2017) premise of a rise in invasive species denialism and to expose to public scrutiny the tactics employed by those who engage in this form of science denialism. As observed by Simberloff (2005), "*For virtually any phenomenon that harms or threatens to harm natural ecosystems, even when the overwhelming majority of expert opinion agrees on the menace, there are always a few individuals who argue that the case is unproven and overblown, that further action is unwarranted for now.*" That is the role that Sagoff (1999, 2000, 2005, 2007, 2011, 2018) has taken for invasive species, and we have shown here that it is fundamentally no different than the role played by those who deny the science of climate change.

Future prospects: a trend unimpeded by evidence

Unfortunately, we foresee no saturation of the rising trend of invasive species denialism. Like other forms of science denialism, it has not abated in the face of increasing knowledge. There seems to be a flourishing market for sensationalist contrarian views in the media and as opinion pieces even in some high-impact journals. We expect that invasive species denialism will increasingly take on subtle forms. Some contrarians, for example, acknowledge the large impacts of a few invasions while downplaying invasion risks in general and suggesting that ecologists' concern over non-native species is based on misguided perceptions and emotional bias (Marris 2011, 2014; Thomas 2017). Marris (2011, 2014) asserted that other stressors such as land development are, by contrast, the real threats, and that investments in managing invasive species "drains time and money away from more constructive conservation projects" (Marris 2011, p. 98)—an opinion that ignores burgeoning evidence of the value and feasibility of eradication and other management interventions to aid native species (e.g. Ratcliffe et al. 2010; Baider and Florens 2011; Griffiths et al. 2015; Jones et al. 2016; Prior et al. 2018). Presenting a false economic choice is a common rhetorical tactic used by contrarians to oppose action on environmental issues; Lomborg (2001) argued that resources dedicated to mitigating climate change should instead be invested in alleviating poverty, and Sagoff (2011) similarly suggested that government investment in managing invasive species problems would be better spent on education or health—as if these were opposing options. Finally, we also expect contrarians to continue to undermine the integrity of invasion ecologists with baseless insinuations that the latter are trained to be prejudiced, view non-native species as "evil" or with hatred (Marris 2011, 2014; Thomas 2017; Pearce 2018) and fuel alarmism to gain research funding (Theodoropoulos 2003; Thompson 2014; Pearce 2015).

So how should ecologists respond to this discourse? Lessons must be learned from other forms of science denialism. Scientists, as many as possible, should participate in the defense of their discipline in the public arena and make the scientific consensus known (Hansson 2018). In addition, the tactics of contrarians engaging in denialism should be exposed (Diethelm and McKee 2009), because explanations of how the science is being distorted would serve both to debunk myths and to inoculate the public against common forms of misinformation (Cook 2016). However, it is important that the public be given broad information about the science and management of invasive species, not just refutations of denialist claims (Hansson 2018).

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