

Viewpoint

What it is to be established: policy and management implications for non-native and invasive species

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Abstract

Management of invasive species, whether prevention, population reduction, or eradication, requires assessment of the invasive species' population status and an assessment of the probability of success of management options. Perceptions of a species' permanence in an environment or lack thereof frequently drives how limited time, financial, and personnel resources are allocated to such efforts. Language we use to describe a non-native species' status largely defines these perceptions and sets boundaries, real or perceived, to potential management actions. Here we discuss the use of a particular term – “established” – when confronting management decisions for invasive species. Our objective is to contribute to bridging the gap between the realms of conceptual development and management with respect to use of the term “established”. We find that although there are benefits of polysemy and synonymy to conceptual development they present an additional challenge to managers who must weigh the costs, benefits, and potential for success of particular management actions. We also examine how existing conceptual frameworks might be augmented to bridge the theoretical-practical gap, such as more precisely defining potential management actions and explicitly including assessment of risk.

Key words: Great Lakes, Galápagos, naturalized

Introduction

Policy and management responses and actions for control or eradication of invasive species are frequently made more challenging by declarations by experts that the species is “established.” The criterion “established” creates a challenge – or perhaps even a problem – for researchers and managers for several reasons. Established is a trigger word among those who manage invasive species and may have to set policy or rules based on laws, one that invokes the idea that there is nothing that can be done. This attitude also may be shared among stakeholders. This may arise from Merriam-Webster's strict lexical definition of established, which includes the word permanent and also includes concepts of “firm and stable” and “beyond doubt” (which may be extended to beyond action), in

addition to the historic use of the term to mean “settled” or “colonized”. The challenge is intensified because the word established is not clearly or consistently defined in laws that govern creation of policies. It also is rarely defined in the scientific literature, and can be used with different meanings even within a publication.

We set out to explore perceptions of what it means for a species to be characterized as established and how policy with respect to adaptive management of invasive species is influenced by it. We will not be developing an epistemological treatise nor prescribing how we believe the term ought to be used. We simply discuss the nature of the term as it is used in ecology of invasive species. For the purpose of this article, we understand an invasive species to be one that is not native (so far as science is able to determine) in

the environment in which it exists, was introduced by some human-mediated means, and causes deleterious biological, economic, or sociological effects. “Environment” in this case may be small (e.g., a 2nd-order watershed) or large (a continent) in scale. The concept of scale is quite relevant to understanding the word established as we discuss below. We do not intend to argue one scale is right or wrong, because our points about the nature of established are scale independent, even if the problems caused by using the word established or by the species in question is not.

The context of our treatment of the word established is the primary importance of socio-political concerns when agencies take action or choose to not act to manage or eradicate an invasive species. We reiterate that understanding of the word established seems to drive concern; established frequently invokes an “all is lost” or “why bother” attitude among resource managers and the publics they serve. One can easily imagine a member of the public asking: “why do you even bother trying to get rid of it if it is already *established*?” Although occasionally declaring an invasive species as established invokes greater need for management, population reduction, or eradication, it is more common for “established” to have the opposite effect. The allocation of funding is determined by the interplay of political, social, and environmental values (Larson et al. 2011). Eradication and efforts to reduce populations require significant time and tax-payer funded resources that could go towards another societal issue. Agencies may abandon these activities in the face of waning public support.

The environmental-social-economic-political context for invasive species management is appreciated by natural resource managers. Consider the decision tree developed and advanced by The Nature Conservancy to guide decisions for implementing management actions for invasive plants (Zimmerman 2011). It begins with a socio-economic question. Biological effects enter into the framework as the 4th question. Davis et al. (2011) argue that strictly biological criteria such as native and non-native fail to acknowledge instances of non-native species benefiting native species and are essentially “old” thinking. They further argue criteria should include harm to economies, ecological services, and human health in addition to biodiversity, with the latter-most being insufficient in and of itself. Larson et al. (2011) argue sustainability is another criterion. The intersection of values regarding what ought to be “controlled,” the capacity to control it, likelihood of success and the authority determines when, if, and how management is to be undertaken (COMTF 2011). “Established” is frequently a trigger word for whether something is perceived to be manageable.

We also note that there are differences to be understood in established as a state of being vs establishment as a process by which something becomes established. Here we focus on the state of being as that is the source of heartburn among managers and many others who develop or whose actions are governed by policy.

Unpacking the term “established”

Nearly all research papers influential in guiding thought about invasion processes and policy that use the words establish, established, or establishment do not explicitly define them. These terms are frequently used as if their meaning is obvious, intuitive, or self-evident. They are frequently used in different contexts in the same paper, e.g., to refer to the status as an invasive species and to refer to a set of laws or guidelines governing a process (e.g., Lodge et al. 2006). They also are frequently used in different ways when referring specifically to an invasive or potentially invasive species. We do not necessarily disagree with Hodges (2008) that such lack of definition and fluidity of concept are beneficial, and perhaps necessary, in the early stages of conceptual development and furthering thought. Perhaps the ambiguity in language is not an unattainable hurdle for managers and the public if “established” is self-evident. But is it?

Richardson et al. (2000) extensively reviewed how language is used in plant invasions focusing on the use of the word “naturalized.” They argued that although many literature-based debates on terminology are largely semantic, those surrounding the use of the term naturalized have real implications. They reported four categories of meaning of the term naturalized: reproduction without human assistance in any environment; reproduction without human assistance in natural or semi-natural environments; synonymous with alien; and synonymous with invasive. Their review implicitly included the term established because established was equated with naturalized in many of the papers they reviewed. Roughly one quarter of the papers they reviewed equated established with the first category of naturalized above. One reviewed paper equated established with survival, which implies becoming established happens rather early in the invasion process. We argue that equating established with merely surviving is inconsistent with the “there’s no hope, so why bother?” understanding of established among members of the public, policy makers, and management agencies. Henderson et al. (2006) also implicitly placed establishment prior to naturalization in stating naturalization occurs when a species becomes self-sustaining

at the point of establishment. Henderson et al. (2006) were referring to plants, individuals of which, for the most part don't move; clearly animals do, hence "point" of establishment might be an area approximately the size of the home range if the organism in question is mobile. On the opposite end of the spectrum, Williamson and Fitter (1996) defined established as "with a self-sustaining population, naturalized," another instance of synonymization of established with naturalized. Kloot (1987) explicitly defined established to be the last stage of naturalization, which might be interpreted as naturalization precedes establishment.

Lodge et al. (2006) provides perhaps the best example of how varied the use of the word established is in the ecological literature. One example is the qualification of established, using the terms initially established, newly established, and well established invasive species. These represent different stages of established and perhaps degrees. The word initial further implies an organism becomes established early in an invasion, consistent with Henderson et al. (2006). They argue eradication is a potential action for newly established but not well-established species. While these distinctions imply benefits to "native" biodiversity and policy of early declaration of established, it is contrary to socio-political perceptions among managers and the public that "established" is the end of the line for eradication and higher-level control and the beginning of mitigation. Lodge et al. (2006) further posit that being established can and frequently does precede spread and impact, which contradicts others who argue established can be scale dependent (see below). Like naturalized, "established" is not well defined even among experts in the field. We re-iterate that we do not disagree with Hodges (2008) that failure to define or imprecise definition is not a theoretical weakness, but it may be a practical one.

A few years prior to Lodge et al. (2006), Heger and Trepl (2003) introduced the notions of spontaneously and permanently established. These expanded the concept of established to include two kinds in addition to degrees and scale of established. Spontaneous implies becoming established is a rapid process early in an invasion (i.e., short time-frame since introduction), which seems consistent with Lodge et al. (2006) that established precedes spread. Permanently established is a curious concept for at least two reasons. First, permanence is an element of the first definition of established. If "established" truly implies permanence, then attempts at removal are necessarily in vain, (note also this might be interpreted as contradicting Lodge et al.'s assertion that newly established can be eradicated but well established cannot). Second, by accepting permanence as a definition of established we fail to acknowledge extinctions. Were Passenger

Pigeon (*Ectopistes migratorius* Linnaeus, 1766) and Dodo (*Raphus cucullatus* Linnaeus, 1758) not established? Or perhaps they were newly established but not well established? It seems established is not permanent or permanence must have temporal and spatial limits, at least within the context of managing invasive species.

Henderson et al. (2006) provide additional thoughts on the notion of scale dependence of established. Their terms first- and second-order established expand the idea of scale; a species can be established here, then expand and become established there. Here and there in this context may also implicitly include additional elements of scale. An invasive species can be first-order established in a watershed and then become second-order established in the adjacent watershed or it can be first order established in Canada and become second-order established throughout North America. This notion is consistent with Ricciardi and Cohen (2007) and others who argue established precedes spread. Using the term established in this sense requires the speaker to responsibly use the smallest possible geographic area when describing *where* a species is established. For example, it is factually correct to say that a species established in the headwaters of Lake Michigan also is established within the Laurentian Great Lakes basin (the former being within the latter), but these two statements evoke very different images of spatial extent, hence the perceived degree of the problem.

Blackburn et al. (2011) remind us that invading species can have deleterious effects and not be established. Clearly that also depends on spatial and temporal scale. They use the example of a single fox on Garden Island in Western Australia (Short et al. 2002). Lake Erie, one of the largest bodies of fresh water on earth, will not be damaged by a single Grass Carp (*Ctenopharyngodon idella* Valenciennes, 1844). If there were just one Grass Carp in Lake Erie, it is likely nobody would ever know. There certainly could not be any deleterious effects at the lake scale. If a single Grass Carp were constrained to a very small embayment or wetland, one might rightly expect a negative effect on local vegetation and the ecological cascade that would follow. On the one hand, if an invading species is detected, is known to have deleterious effects, is low in abundance, and can be greatly reduced in numbers or even eradicated, this can be a good scenario for a manager. On the other hand, if a species can have deleterious effects and not be established, is being established (or is that naturalized?) simply semantic as Richardson et al. (2000) cautioned?

Returning briefly to the synonymization of naturalized and established, among managers these terms

have different meanings. Naturalized is becoming increasingly used as a term to refer to a non-native species that has limited negative ecological effects or perhaps a net positive effect. Pacific salmonids in the Laurentian Great Lakes are an excellent example. They are not native, several species were stocked deliberately (Parsons 1973) to reduce populations of invasive Alewife (*Alosa pseudoharengus* Wilson, 1811), and they support recreational fisheries throughout the region. Are these salmonid species “established?” Probably. Natural reproduction has been documented for several species (Parsons 1973; Thompson and Ferreri 2002), but they are generally not considered invasive, and the term naturalized is used to describe their status [Eshenroder et al. (1995); curiously, this document also lists Common Carp (*Cyprinus carpio* Linnaeus, 1758) as naturalized although it certainly qualifies as invasive and has little, if any, positive economic value). The distinction between naturalized and established may be a non-sequitur to theoreticians, but it is becoming a real and possibly necessary distinction to managers.

To briefly summarize a subset of highly influential literature, we have different *kinds* of established (spontaneous vs permanent), *degrees* of established (newly, well, primary, secondary), geographic *scales* of establishment (here and there), established without deleterious effects, and deleterious effects without being established. It’s no wonder managers have heartburn over the term.

Should we bother with a definition?

Given the befuddled nature of the term established, ought there be a firm definition? A couple of attempts have been made. Shafland and Lewis (1984) explicitly defined established as permanent and not likely to be eradicated by either natural causes or human attempts. They do not address what criteria might apply that would permit a conclusion of permanence. Kloot’s (1987) definition included the criteria widespread (broad spatial scale) and “reproducing freely”. He adds the caveat that a plant with a limited distribution that has persisted for 25 years (long temporal scale) is established. Williamson and Fitter (1996, Table 1) defined established as “with a self-sustaining population, naturalized”. A recent risk assessment for Grass Carp in the Laurentian Great Lakes (Cudmore et al. 2017) stops just short of defining established. The authors approach a definition by couching it in other concepts: a *self-sustaining* population is established, and a self-sustaining population is defined as *reproduction by naturally-reproduced individuals*. This quasi-definition is intuitively satisfying for at least two reasons. First, it is consistent

with some of the literature in that the state of being established requires repeated successful reproduction. This is consistent with Kloot’s (1987) definition for plants. Second, ecologically, fitness is understood to be, or maybe even defined as, production of reproducing offspring. A weakness is that a constant source of newly introduced individuals might also contribute to reproduction whether or not their progeny reproduce, which could, in theory, sustain a non-native population sufficiently long to meet Kloot’s definition of 25 or more years. By this definition, a population that has demonstrated ecological fitness may be declared established – or perhaps “newly established” or “first-order established” or “initially established” to use concepts presented previously. Of course, there is no need to define established if a population’s reproductive success is simply described in those terms; however, it must be acknowledged that saying “established” is much easier (although less precise) than saying “reproduction by naturally-reproduced individuals” or “multi-generational reproductive success,” and this type of succinct communication is common among managers and policy makers. There may be other definitions in the literature, but these suffice to demonstrate there is some consistency (natural reproduction) but also variation (widespread, synonymized with naturalized) in published definitions.

Hodges (2008) cautions there are great risks to narrowly defining ecological terms. Her arguments against efforts to standardize or define terms include stunting conceptual development, that polysemy and synonymy do not necessarily result in conceptual befuddlement (and frequently do not) or lack of understanding between authors and readers, and that categorization of and imposition of boundaries on continuous processes, such as invasions, may end up being arbitrary. An example of the benefit of imprecisely defined or undefined terms comes from the field of law. Laws frequently include intentionally undefined terms to permit latitude in interpretation. Case law is the mechanism through which legislated laws achieve clarity (akin to Hodges’s (2008) context mechanism whereby words obtain meaning). An excellent example is the term “practicable” in the uniform vehicle code (UVC; League of American Bicyclists 2000). Practicable is not defined in any dictionary or the UVC. The term “practicable” leaves wiggle room in the event a case is brought before a court for interpretation. What is practicable depends on the context of individual cases.

For invasive species control and whether a species is established, arguments can be made both ways for definition being beneficial or detrimental. One might argue the concepts of newly established and first-order established and initially established permit

interpretation that become clearer as case studies inform processes (much as case law clarifies understanding). One might also argue they just muddy the waters by adding two more levels of complexity. For managers of invasive species, it is not about conceptual development or epistemology or philosophy, it is about defending decisions to spend/not spend the public's money, which integrate political, ethical, economic, aesthetic, and other values, to combat invasive species. When concepts must be translated into actions, and when the public judges those who act, tension arises for those who manage invasive species. In this context, a strict definition might be viewed as required.

Assuming for the moment a more rigid definition has merit, and further assuming the concepts presented above relating to reproduction and ecological fitness are relevant to determining if a species is established, achieving those criteria can be challenging and leaves its own wiggle room. For example, observing multiple generations and repeated reproduction can sometimes be difficult to demonstrate and may even be interpreted differently. For some species there is little room for interpretation. Species with 1-year life cycles [e.g., annual grasses (Poaceae); most populations of Emerald Ash Borer (*Agrilus planipennis* Fairmaire, 1888)] must reproduce annually to not go extinct. For those that live a decade or longer (e.g., goats *Capra aegagrus hircus* Linnaeus, 1758) or have extended larval or pupal periods (e.g. 13- and 17-year Cicadas *Magicicada* spp.) that need to reproduce only occasionally to persist, there is wiggle room. Irregular reproduction, or strong-weak reproductive periodicity, permit some interpretation as to whether reproduction is sufficiently regular to conclude "established." For some species, observing reproduction of naturally reproduced individuals is a challenge in and of itself. A species might be considered established based on the definition and not be known to be established simply because managers and researchers lack the capacity or data to observe it.

Where ecology meets policy: how "established" affects management

Managers are the front-line control agents for invasive species. They're the ones who have to make difficult decisions on how to spend finite public resources to achieve multiple management goals that meet the public's best interest. In the US, state fish and wildlife agencies, tribal governments, county, and local units of government are typically charged with invasive species management. This arrangement creates a secondary challenge when state agencies conduct management, because these agencies are

funded primarily by excise taxes on hunting and fishing equipment. Their primary public is consumptive users of resources. With a narrow view, one could argue management agencies ought not be expending any money combating invasive species. More practically, if invasive species are reducing populations of or damaging habitat for exploited species, some of which themselves may be non-native, then limited expenditures are justified. We do not intend to debate the positives and negatives of this funding model with respect to invasive species management, but it is a factor that affects decisions on where, when, how, and if invasive species are managed in the US.

When faced with a decision to spend or not to spend on combating an invasive species, established is frequently the line that, if crossed, indicates efforts to eradicate ought to cease. This is certainly not exclusively the case as managers' and the public's attitude toward combating invasive species has been evolving as the onslaught of invasive species has continued. But we argue that more often than not, when a species is deemed "established" the option of eradication is effectively lost. Returning to the lexical definition of established, if a species is established it has permanence in a particular location. Permanence can be rightly interpreted by those whose money is being spent to mean something can't be exterminated. Despite the fact there are counter-examples of species that meet Kloot's (1987) definition and the criteria of Cudmore et al. (2017), we argue such cases are exceptions. Goats on Santiago Island, one of the Galápagos Islands, are one example (Cruz et al. 2009). They were exterminated despite meeting criteria for established set out above. It took significant international action and diverse funding sources to accomplish the eradication. Goats are also comparatively easy to see, can be killed from long distances with high-powered rifles, and have limited ability to recover from population declines compared to many plants and some vertebrates. This eradication also was undertaken on an island. Few invasive species, plant or animal, offer the opportunity for complete success.

The words used to characterize the status of an invasion also have consequences for the funding of management activities. Specific amounts of funding may be directed to discrete timeframes in an invasion. For example, in the US, the Great Lakes Restoration Initiative (GLRI) has provided funds to many Federal, State, Tribal, and local agencies to combat invasive species in the Laurentian Great Lakes. There are three main categories of activity that are funded: prevention, rapid response, and control. "Prevention" activities are those directed toward species not currently present in the Great

Lakes ecosystem and typically involve attempts to block a pathway of introduction. “Rapid Response” activities are directed toward those species which are 1) present in a limited geographic area and 2) the jurisdictional authority is, or will be, implementing a response with the goal of eradication. (A rapid response effort is over when the jurisdictional authority concedes that eradication is not achievable.) “Control” activities are those directed toward common and wide-spread species, with the goal of mitigating the impacts of the species at specific ecologically or economically important sites. In the context of GLRI, the word “established” is used when discussing the control of common and widespread invasive species, e.g., there is an objective to “control established invasive species”. Invasive species managers must be aware of the terminology used in the relevant funding program when seeking and using these resources.

This conundrum of the use of established with respect to policy and management options versus its use in research and conceptual development might be formulated as the Policy Paradox: early *detection and action* are keys to successful management – whether eradication, control, or any level in-between – of invasive species, but early *designation as established* may hinder what can be done. This is especially true if the species is said to be established in large geographic areas (e.g., within a multi-state ecosystem) rather than established within narrow geographic boundaries (i.e., the actual extent of the population). Whether we can or should precisely define established may be interesting academically, but in the context of implementation of policy, use of the term established has immediate consequence. More precise use of the term established [or naturalized as presented by Richardson et al. (2000)] has real management consequences.

Classification schemes created by ecologists have been useful in advancing understanding of the invasion process. Two of the most widely cited frameworks (e.g., Colautti and MacIsaac 2004; Blackburn et al. 2011) eschew stating precisely when an invading species achieves the status of established, and instead identify a range of stages in the invasion process when establishment probably occurs. In the Colautti and MacIsaac (2004) framework, established occurs among stages III–V of their framework, which begins after survival and reproduction. Aside from declaring that managers require clear objectives and models and invoking the potential for undermining the efforts of managers, they do not address how a designation of established affects management actions or decisions. Blackburn et al. (2011) were the first to attempt to merge the ecological processes and terminology

of invasion with associated management actions. They also accomplished development of a unified framework integrating vegetation-centric (Richardson et al. 2000) and animal-centric (Williamson 1996) frameworks. Blackburn et al. (2011) designate an establishment stage that includes survival and reproduction, and the term “naturalized/established” spans from between survival and reproduction within the establishment stage through the spread stage (Blackburn et al. 2011, Figure 1). They assign eradication as a management action beginning within the introduction stage and extending through the spread stage. Containment as a management option bridges the establishment/spread boundary. Mitigation is an option only during the latter part of the spread stage.

Although a leap forward, the Blackburn et al. (2011) framework is lacking when confronted with the realities of management of invasive species at broad scales. While leaving open the option of eradication despite a declaration of “established” sounds appealing and is theoretically possible (recall the Galápagos goats), in practice eradication *as a stated management objective* is a less-likely option when scarce resources, which must be used to manage every category of native and non-native species, are chasing a potentially endless battle. We don’t mean to argue that all attempts to eradicate or greatly reduce populations of invasive species are hopeless and endless, but it is generally not possible to know in advance which attempts to eradicate have a chance and which don’t. Sea Lamprey (*Petromyzon marinus* Linnaeus, 1758) has been targeted for control in the Laurentian Great Lakes for over 50 years. Dozens of streams are treated annually with tens of thousands of kilograms of lampricides to kill Sea Lamprey before they can recruit to the adult stage (Mullett and Sullivan 2017). Ceasing or just reducing control efforts for even a short period of time allows populations to grow (Adair and Sullivan 2011). Multiflora rose (*Rosa multiflora* Thunberg, 1784) and tree of heaven [*Ailanthus altissima* (Miller) Swingle, 1916] are similar terrestrial plant examples with invasive populations in North America, Asia, Europe, and Australia. These three species are certainly established regardless of how permissive or restrictive a definition is imposed, and eradication at broad scales by management agencies is not a reasonable, economically acceptable option. In theory, a long-term, spatially extensive program in which every Great Lakes tributary is treated for a few decades might result in complete eradication of Sea Lamprey. But the will is lacking to make that level of effort. Sea Lamprey are established. For tree of heaven and multiflora rose, financial cost-sharing programs funded by public resources exist to assist individual

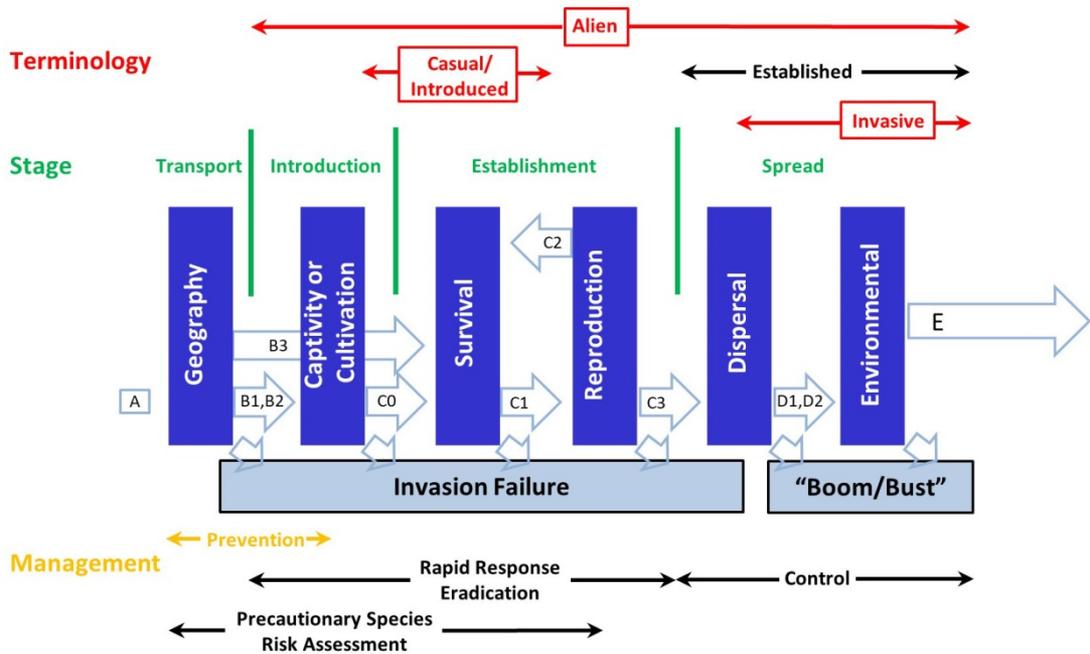


Figure 1. Proposed framework modified from Blackburn et al. (2011; Figure 1) for management alternatives for non-native and invasive species. Abbreviations for transitions between stages are defined in Blackburn et al. Table 1. Approximate color schemes from Blackburn et al. are retained with our changes in black text.

land-owners to eradicate these species (e.g., US Department of Agriculture Environmental Quality Incentives Program), and efforts to eradicate at small scales can succeed, provided landowners are committed to continuous treatment to eliminate new individuals (because there are sources of new invaders from surrounding properties). Eradication, for all practical purposes, is eliminated as a management option at broad scales once a species has been declared as established.

For the purpose of management, it is indeed important, as others before us have pointed out, to have a more precise meaning of “established.” The quasi-definition provided in Cudmore et al. (2017) provides both clarity of thought and wiggle room for devising management actions. The high burden of proof of *demonstrating* natural reproduction of naturally-reproduced individuals ensures managers maintain a breadth of options for managing a non-native species. Demonstrating individuals were the result of natural reproduction of naturally reproduced individuals will be easy for some species (e.g. tree of heaven) and more difficult for others (e.g., Grass Carp). Although seemingly rigid, “demonstrate” leaves some room for

interpretation. Even scientists will tolerate up to a 5% or 10% chance of error when conducting a typical parametric statistical test. Applying that same logic qualitatively to reproductive scenarios, even if one can imagine a scenario under which reproduction might have been the result of a non-naturally-reproduced individual, if the broad pool of evidence strongly points toward reproduction of naturally reproduced individuals, then the logical leap might be justified even if the best confirmatory evidence is lacking. We admit that to purists “confirmatory” and science don’t mix, and we won’t argue that point. But science is not the only tool in the manager’s toolbox, and to the public, confirmation has merit.

The Cudmore et al. (2017) quasi-definition of established fits the descriptive approach posited in the Colautti and MacIsaac (2004) framework in the range of stages they specified (stages III–V). No revision of this framework would be required to be more useful for management purposes. Revision of the Blackburn et al. (2011) framework would be required (Figure 1). First, the left terminus for naturalized/established would have to slide to the right to after the reproduction barrier. We re-name it

“established” here owing to the emerging differences in uses of naturalized and established among managers (see next paragraph). Second, the right terminus of eradication as a management option would have to slide to between the reproduction and dispersal barriers. Rapid responses to new invasions align with eradication.

Our first alteration brings us back to the notion of whether established and naturalized are indeed equivalent terms as presented in the Blackburn et al. (2011) framework. They may not be, but separating them is no easy task. If we follow Kloot (1987), who defined established as the last stage of naturalization, one might be tempted to think of naturalized as preceding established. The lexical definition of naturalize as a transitive verb, “to cause to become established as if native,” can be interpreted to support that conclusion. But returning to Hodges (2008) cautionary note about categorizing continuous things and Kloot’s (1987) definition, naturalization is a process, hence continuous, and making the categories “naturalized” and “established” within that process may be arbitrary. Managers have something to gain by having naturalized and established as different categories, and based on examples above it seems these terms may be finding their distinction among managers.

An important omission in these frameworks is risk assessment as a management tool. Risk assessment informs prevention, which is the first and most effective step at managing a potentially invasive species by ensuring it never enters an environment. Risk assessment also informs management options, such as whether to pursue eradication or containment, if a species enters a new environment. Lodge et al. (2006) recommended risk assessments as part of a comprehensive plan for assessment and management of invasions. Both Colautti and MacIsaac (2004) and Blackburn et al. (2011) cited at least one paper on risk assessment, but did not include it in their frameworks. Risk assessment belongs ideally at stage 0 of the Colautti and MacIsaac framework, but still has useful application through stage I. In the Blackburn et al. (2011) framework, risk assessment is applicable during the transport, introduction, and establishment stages (Figure 1). We also add identification and screening of precautionary species that have likely climate and habitat matches with environments they might invade.

Summary

We are not among the experts in the ecology of invasions, although we have published on invasive species and their management (e.g., Kočovský et al. 2011; Chapman et al. 2013; Davidson et al. 2016).

We are among those with expertise in conducting research that leads to management actions in our fields, in helping to manage the information that informs what is invasive and what is or is not established, and in guiding policy decisions. We did set out to address how established is used with the intent of clarifying language to assist resource managers with policy-related decisions and management actions dictated or guided by them. The quasi-definition of established provided in Cudmore et al. (2017) effectively accomplishes the goal of drawing a “line” that has to be crossed that assists managers in their work.

We did not set out to create yet another framework to guide research, management, outreach or communication of invasive species, yet our review may have effectively done so in pointing out the weakness of omission of risk assessment. Perhaps risk assessment is not critical to understanding the ecological process of invasion and what is or is not established, but for management it is valuable and potentially necessary step. In conclusion, we acknowledge the advantage of ease of use of “established” as a shorthand for lengthy, jargon-laden alternatives such as “multi-generational reproductive success”, the advantages of its use as a categorical concept avoiding splitting the term into a myriad of sub-categories such as “initial local establishment”, and the advantage of such polysemy in allowing context-specific flexibility in application. We caution those using the term to provide some guidance to readers, particularly management and policy readers, of their meaning within the particular context in order to avoid having inappropriate conclusions drawn from their work.

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References

- Adair R, Sullivan P (2011) Integrated management of Sea Lampreys in the Great Lakes, 2010. Annual report to the Great Lakes Fishery Commission, Ann Arbor, Michigan, 99 pp

- Blackburn TM, Pyšek P, Bacher S, Carlton JT, Duncan RP, Vojtěch J, Wilson JR, Richardson DM (2011) A proposed unified framework for Biological Invasions. *Trends in Ecology and Evolution* 26: 333–339, <https://doi.org/10.1016/j.tree.2011.03.023>
- Chapman DC, Davis JJ, Jenkins JA, Kočovský PM, Miner JG, Farver J, Jackson PR (2013) First evidence of Grass Carp recruitment in the Great Lakes Basin. *Journal of Great Lakes Research* 39: 547–554, <https://doi.org/10.1016/j.jglr.2013.09.019>
- Colautti RI, MacIsaac HJ (2004) A neutral terminology to define ‘invasive’ species. *Diversity and Distributions* 10: 135–141, <https://doi.org/10.1111/j.1366-9516.2004.00061.x>
- COMTF (2011) A Decision-making Guide for Invasive Species Program Managers. <http://www.suddenoakdeath.org/wp-content/uploads/2011/04/DM-Guide-for-Invasive-Species-Program-Managers-Final-May-2011.pdf> (accessed 21 August 2017)
- Cruz F, Carrion V, Campbell KJ, Lavoie C, Donlan CJ (2009) Bioeconomics of large-scale eradication of feral goats from Santiago Island, Galápagos. *Journal of Wildlife Management* 73: 191–200, <https://doi.org/10.2193/2007-551>
- Cudmore B, Jones LA, Mandrak NE, Dettmers JM, Chapman DC, Kolar CS, Conover G (2017) Ecological Risk Assessment of Grass Carp (*Ctenopharyngodon idella*) for the Great Lakes Basin. DFO Canadian Science Advisory Secretariat Research Document. 2016/118. vi + 115 p
- Davidson AD, Fusaro AJ, Sturtevant RA, Rutherford ES, Kashian DR (2016) Development of a risk assessment framework to predict invasive species establishment for multiple taxonomic groups and vectors of introduction. *Management of Biological Invasions* 8: 25–36, <https://doi.org/10.3391/mbi.2017.8.1.03>
- Davis MA, Chew MK, Hobbs RJ, Lugo AE, Ewel JJ, Vermeij GJ, Brown JH, Rosenzweig ML, Gardener MR, Carroll SP, Thompson K, Pickett STA, Stromberg JC, Del Tredici P, Suding KN, Ehrenfeld JG, Grime JP, Mascaro J, Briggs JC (2011) Don’t judge species on their origins. *Nature* 474: 153–154, <https://doi.org/10.1038/474153a>
- Eshenroder RL, Holey ME, Gorenflo TK, Clark RD Jr (1995) Fish Community Objectives for Lake Michigan. Great Lakes Fishery Commission Special Publication 95-3, 56 pp
- Heger T, Trepl L (2003) Predicting biological invasions. *Biological Invasions* 5: 313–321, <https://doi.org/10.1023/B:BINV.0000005568.44154.12>
- Henderson S, Dawson TP, Whittaker RJ (2006) Progress in invasive plants research. *Progress in Physical Geography* 30: 25–46, <https://doi.org/10.1191/0309133306pp468ra>
- Hodges KE (2008) Defining the problem: terminology and progress in ecology. *Frontiers in Ecology and the Environment* 6: 35–42, <https://doi.org/10.1890/060108>
- Kočovský PM, Tallman JA, Jude DJ, Murphy DM, Brown JE, Stepien CA (2011) Expansion of tubenose gobies *Proterorhinus semilunaris* into western Lake Erie and potential effects on native species. *Biological Invasions* 13: 2775–2784, <https://doi.org/10.1007/s10530-011-9962-5>
- Kloot PM (1987) The naturalised flora of South Australia 1. The documentation of its development. *Journal of the Adelaide Botanic Garden* 10: 81–90
- Larson DL, Phillips-Mao L, Quiram G, Sharpe L, Stark R, Sugita S, Weiler A (2011) A framework for sustainable invasive species management: Environmental, social, and economic objectives. *Journal of Environmental Management* 92: 14–22, <https://doi.org/10.1016/j.jenvman.2010.08.025>
- League of American Bicyclists (2000) Uniform Vehicle Code Revised 2000 Annotated for MUTCD 7/26/10. <http://bikeleague.org/sites/default/files/UVC%20Definitions.pdf> (accessed 21 August 2017)
- Lodge DM, Williams S, MacIsaac HJ, Hayes KR, Leung B, Reichard S, Mack RN, Moyle PB, Smith M, Andow DA, Carlton JT, McMichael A (2006) Biological Invasions: recommendations for US policy and management. *Ecological Applications* 16: 2035–2054, [https://doi.org/10.1890/1051-0761\(2006\)016\[2035:BIRFUP\]2.0.CO;2](https://doi.org/10.1890/1051-0761(2006)016[2035:BIRFUP]2.0.CO;2)
- Mullett K, Sullivan P (2017) Sea Lamprey control in the Great Lakes 2016. Annual report to the Great Lakes Fishery Commission, Ann Arbor, Michigan, 108 pp
- Parsons JW (1973) History of salmon in the Great Lakes, 1850-1970. U.S. Bureau of Sport Fisheries and Wildlife, Ann Arbor, MI, 80 pp
- Ricciardi A, Cohen J (2007) The invasiveness of an introduced species does not predict its impact. *Biological Invasions* 9: 309–315, <https://doi.org/10.1007/s10530-006-9034-4>
- Richardson DM, Pyšek P, Rejmánek M, Barbour MG, Panetta FD, West CJ (2000) Naturalization and invasion of alien plants: concepts and definitions. *Diversity and Distributions* 6: 93–107, <https://doi.org/10.1046/j.1472-4642.2000.00083.x>
- Shafland PL, Lewis WM (1984) Terminology associated with introduced organisms. *Fisheries* 9(4): 17–18
- Short J, Kinnear JE, Robley A (2002) Surplus killing by introduced predators in Australia – evidence for ineffective anti-predator adaptations in native prey species? *Biological Conservation* 103: 283–301, [https://doi.org/10.1016/S0006-3207\(01\)00139-2](https://doi.org/10.1016/S0006-3207(01)00139-2)
- Thompson, BE, Ferreri CP (2009) Population biology of steelhead spawning runs in three Pennsylvania tributaries to Lake Erie. *Journal of Great Lakes Research* 28: 264–275, [https://doi.org/10.1016/S0380-1330\(02\)70582-0](https://doi.org/10.1016/S0380-1330(02)70582-0)
- Williamson M (1996) Biological Invasions. Springer, The Netherlands, 244 pp
- Williamson M, Fitter A (1996) The varying success of invaders. *Ecology* 77: 1661–1666, <https://doi.org/10.2307/2265769>
- Zimmerman C (2011) To Control or Not to Control? An Invasive Plant Management Decision Analysis Tool. <https://www.conservationsgateway.org/News/Pages/control-or-not-control-in.aspx> (accessed 21 August 2017)