



Clarifying values, risk perceptions, and attitudes to resolve or avoid social conflicts in invasive species management

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Abstract: *Decision makers and researchers recognize the need to effectively confront the social dimensions and conflicts inherent to invasive species research and management. Yet, despite numerous contentious situations that have arisen, no systematic evaluation of the literature has examined the commonalities in the patterns and types of these emergent social issues. Using social and ecological keywords, we reviewed trends in the social dimensions of invasive species research and management and the sources and potential solutions to problems and conflicts that arise around invasive species. We integrated components of cognitive hierarchy theory and risk perceptions theory to provide a conceptual framework to identify, distinguish, and provide understanding of the driving factors underlying disputes associated with invasive species. In the ISI Web of Science database, we found 15,915 peer-reviewed publications on biological invasions, 124 of which included social dimensions of this phenomenon. Of these 124, 28 studies described specific contentious situations. Social approaches to biological invasions have emerged largely in the last decade and have focused on both environmental social sciences and resource management. Despite being distributed in a range of journals, these 124 articles were concentrated mostly in ecology and conservation-oriented outlets. We found that conflicts surrounding invasive species arose based largely on differences in value systems and to a lesser extent stakeholder and decision maker's risk perceptions. To confront or avoid such situations, we suggest integrating the plurality of environmental values into invasive species research and management via structured decision making techniques, which enhance effective risk communication that promotes trust and confidence between stakeholders and decision makers.*

Keywords: biological invasions, cognitive hierarchy theory, non-native species, publication trends, risk analysis, science and society, social dimensions

Clarificar los Valores, Percepciones de Riesgo y Actitudes para Resolver o Evitar Conflictos Sociales en el Manejo de Especies Invasoras

Resumen: *Las personas que toman las decisiones y los investigadores reconocen que existe una necesidad para enfrentar efectivamente las dimensiones sociales y los conflictos inherentes a la investigación y el manejo de las especies invasoras. Sin embargo, pese a numerosas situaciones conflictivas que han surgido, ninguna evaluación sistemática de la literatura ha examinado los aspectos de la gente común en los patrones y tipos de*

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estos problemas sociales emergentes. Al usar palabras clave de los campos sociales y ecológicos, revisamos las tendencias en las dimensiones sociales en la investigación y manejo de las especies invasoras, y en las fuentes y soluciones potenciales a los problemas y conflictos que surgen alrededor de las especies invasoras. Integramos componentes de la teoría de la jerarquía cognitiva y la teoría de la percepción del riesgo para proporcionar un marco de trabajo conceptual que permita identificar, distinguir y proporcionar un entendimiento de los factores que conducen a disputas subyacentes asociadas con las especies invasoras. En la base de datos ISI Web of Science, encontramos 15,915 publicaciones revisadas por colegas sobre invasiones biológicas, 124 de las cuales incluyeron a las dimensiones sociales de este fenómeno. De estas 12,428 estudios describieron situaciones conflictivas específicas. Han emergido estrategias sociales para las invasiones biológicas, en su mayoría en la última década, que se han enfocado tanto en las ciencias sociales ambientales y como en el manejo de recursos. A pesar de estar distribuidas en una gama de revistas, estos 124 artículos se concentraron en su mayoría en medios orientados a la ecología y la conservación. Encontramos que los conflictos que rodean a las especies invasoras, en su mayoría, surgieron con base en las diferencias en los sistemas de valuación y en un menor grado, en las percepciones de los accionistas y quienes toman las decisiones. Para enfrentar o evitar dichas situaciones, sugerimos integrar la pluralidad de los valores ambientales a la investigación y el manejo de las especies invasoras por medio de técnicas de toma de decisiones, las cuales mejoran la comunicación efectiva de riesgo, que promueve confianza y seguridad entre los accionistas y quienes toman las decisiones.

Palabras Clave: análisis de riesgo, CHT, ciencia y sociedad, dimensiones sociales, especies no-nativas, invasiones biológicas, tendencias de publicación, teoría de la jerarquía cognitiva

Introduction

The terms *native*, *exotic*, and *invasive* as applied to biological species are in part social constructions of the ways we understand nature, informed by scientific data and cultural norms (Binimelis et al. 2007). As such, their meaning and significance have varied over time and among social groups (Carruthers et al. 2011). Ultimately, a complex combination of ecology, mental representations, and social contexts influence the construction of a species' status (Fischer & van der Wal 2007). Indeed, reviewing the academic literature, Woods and Moriarty (2001) showed that in numerous instances even the scientific community ambiguously distinguishes these terms, and species considered native for a geographical area can be considered non-native at some point.

Given the interplay of multiple perspectives by different stakeholders regarding these social and ecological dimensions of species, invasion biology has confronted problematic situations and even direct public opposition (McNeely 2001; Rotherham & Lambert 2011), which is also the case in the broader field of conservation science (Redpath et al. 2013). For example, numerous exotic species that are considered invasive by some social sectors are simultaneously recognized by others as providing valuable ecosystem services or cultural benefits or as having intrinsic worth (McNeely 2001; Schlaepfer et al. 2011). Resulting social clashes can obstruct planned control efforts and demonstrate the practical need to ensure public support for successful management projects (Perry & Perry 2008).

Within academia, a native is good versus exotic is bad dichotomy has been expressed in contentious debates in the invasion biology sub-discipline (e.g., Larson 2005; Simberloff 2012). This focus is also reflected

in the literature produced largely by natural scientists gathering information for control and eradication programs that concentrates on describing the autecology of invasive exotic species and their negative impacts on native biota and ecosystems (Simberloff et al. 2013; Anderson & Valenzuela 2014). For both conceptual and practical reasons, though, it has become increasingly clear that as a socio-ecological process the research and management of biological invasions must incorporate social considerations (Lodge & Shriver-Frechette 2003; Larson et al. 2011). To date, however, no evaluation has examined commonalities and differences in the patterns and types of these social issues. Therefore, we reviewed and analyzed bibliographic trends in the social dimensions of invasive species research and management and explored the sources and potential solutions to problems and conflicts that arise around invasive species.

Framing Values, Risk Perceptions, and Attitudes toward Invasive Species

Humans have a long and intimate history with introduced species, and symbolic and utilitarian links have been formed between these species and our societies. As early as 270 BCE, the Egyptians brought flora and fauna from elsewhere for botanical and zoological gardens (Hughes 2003). Likewise, the Romans imported crocodiles, lions, and elephants for entertainment and aesthetics (Hughes 1975). In 18th and 19th centuries, European colonial mindsets created novel socio-ecological systems with species translocations to evoke cultural and sentimental features that reminded migrants of their former homes (Mack 2001). In the 20th and 21st centuries, the spread of

organisms around the globe has attained unprecedented levels and is facilitated by international trade, intercontinental transportation, and global markets (Meyerson & Mooney 2007). A subset of non-native species are classified as invasive species based on their potential for economic, ecological, or other types of damage (GISP 2001).

Social science research shows that human attitudes and behaviors toward nature and natural resource management, such as invasive exotic species and their control, are multiple and diverse and are affected by psychological, cultural, and evolutionary factors (Kaplan & Kaplan 1989; Gobster 2011). In turn, underlying beliefs and perceptions about invasive species have been explained by individual or group demographics and knowledge and properties of the organism itself (e.g., aesthetic, charisma) (Bremner & Park 2007; García-Llorente et al. 2011). Given the interplay of these myriad issues, in any given situation it is difficult a priori to predict someone's response to a particular management policy. Nevertheless, humanists and social scientists have found that a few core principles and cognitive structures, including values systems and risk perceptions, are fundamental components that frame subsequent attitudes and help explain ultimate behavior toward invasive species (Churchill et al. 2002; Fischer & van der Wal 2007; Norgaard 2007).

Cognitive hierarchy theory (CHT) is a conceptual framework that organizes values, attitudes, and behaviors as a tiered system and has been commonly applied to support natural resource management (Fulton et al. 1996; McFarlane & Boxall 2003; Whittaker et al. 2006). Values are the CHT's central level and are understood as enduring and fundamental beliefs that influence attitudes and guide behaviors (Rokeach 1973). Attitudes, in turn, are numerous and flexible constructs based on several beliefs and value trade-offs that involve preferences or evaluations in specific situations (Fulton et al. 1996). In the last level of the CHT framework, behaviors are understood as intention of action and as being directly influenced by attitudes (Rokeach 1973).

Despite its theoretical strengths in linking values, attitudes, and behavior with environmental management actions, the CHT does not explicitly incorporate other important factors such as risk perceptions. In confronting difficult decisions, cognitive psychology studies have demonstrated that people frequently make judgments based on a set of mental strategies—or heuristic rules—that reduce complex mental tasks to simpler ones. Furthermore, risk management perceptions are influenced by common mental mechanisms, such as evaluation of potential hazards and lack of institutional or personal trust (Slovic 1999). These cognitive processes may generate substantial and persistent biases and lead to attitudes that misinterpret the magnitude or severity of risks (Burgman 2005).

Currently, cultural cognition theory, based on the early works of Douglas and Wildavsky (1982), informs

the integration of these 2 frameworks and shows that individuals also form their risk perceptions based on their cultural backgrounds and personal values (Kahan & Braman 2006). The relevance of connections between value systems and risk perceptions has been confirmed, for example, in the construction of attitudes about nanotechnology (Kahan et al. 2009). Regarding environmental risk perceptions, Slimak and Dietz (2006) found that an individual's values and fundamental beliefs explain how the individual perceives potential risks. Therefore, integrating risk perceptions with CHT can help further clarify interpretations and evaluations of potential hazards, which also affect the construction of attitudes (Slovic 1999; Lazo et al. 2000). Under this integrated framework, attitudes and behaviors are influenced by underlying values and the cognitive evaluation of a situation based on culture or risk perception. We believe that clarifying these cognitive structures may reduce or help avoid conflicts in conservation and management.

Here, we sought to provide a holistic understanding of biological invasions as a socio-ecological phenomenon. We used the integrated frameworks provided by CHT and risk perception theories (Fig. 1) to examine the underlying causes of conflicts related to the way scientists, managers, and society react to invasive species and their management. Specifically, we explored bibliometric trends in publications that use social science approaches to biological invasions; characterized conflicts in invasive species research and management; and developed suggestions about how conflictive situations can be confronted constructively at the decision-making interface with society. Our broad hypothesis is that the integrated CHT and risk perception framework and our socio-ecological approach to invasive species research and management may be used as tools to address existing conflicts and to conduct more relevant and targeted scientific research into biological invasions and offer practical solutions to anticipate and avoid confrontations in the future.

Methods

We conducted a systematic search of the peer-reviewed literature that addresses values, risk perceptions, attitudes, and conflicts in the study and management of invasive exotic species. Publications were identified through the ISI Web of Science (WOS) database from 1 January 1980 to 1 January 2013. We combined 14 biological keywords (*alien plant**, *alien species*, *bioinvasion**, *biological invasion**, *exotic animal**, *exotic plant**, *exotic species*, *feral animal**, *invasion biology*, *invasive plant**, *invasive animal**, *invasive species*, *non-indigenous species*, *nonnative species*) with 5 social keywords (*attitude**, *perception**, *ethic**, *values AND social*, *conflict* AND social*). All queries were combined (OR) to avoid duplication of articles.

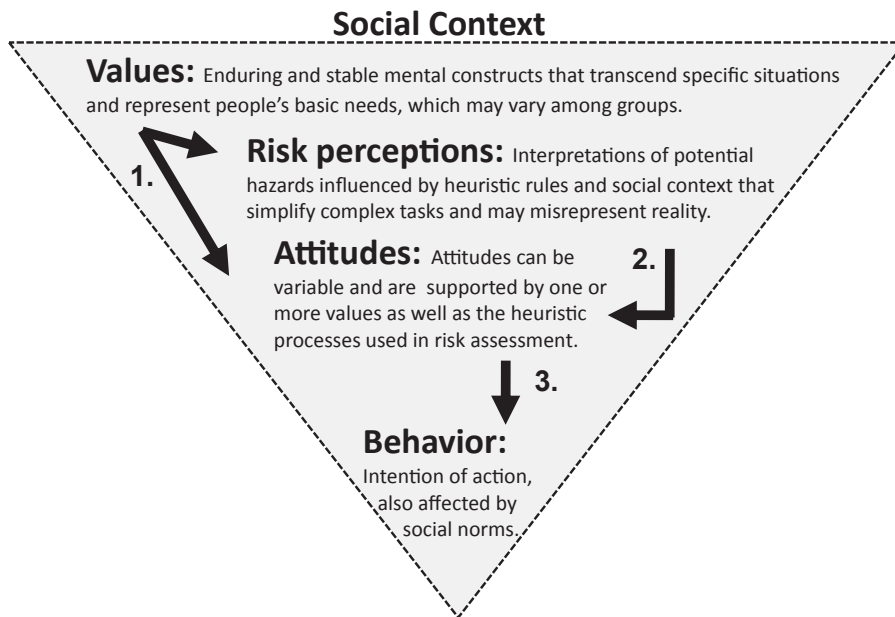


Figure 1. A conceptual framework to understand social perceptions of invasive species created by integrating cognitive hierarchy theory (CHT) and risk perception theories. The framework is based on an explicit identification and recognition of (1) values (i.e., enduring and stable beliefs that are the basis of the hierarchy), (2) attitudes supported by one or more values and affected by risk perception, and (3) behaviors resulting directly from constructed attitudes based on elements of the CHT and the heuristic processes inherent in risk perceptions.

This search resulted in 327 papers. We read the abstracts of these papers and identified a subset of 99 papers about biological invasions that incorporated social dimensions. The 228 articles that did not include social topics in the analysis were excluded. Because our first set of search criteria likely left out relevant papers that did not include our filter terms explicitly in the title, abstract, or keywords, we assessed the references of the remaining 99 papers and discovered another 25 relevant papers also available in the WOS database.

Using the final database of 124 articles, we classified each by research category; year of publication; journal; first author's institutional location (continent); study site location (continent); and taxonomic group studied. Research category was divided into the following subcategories: environmental social science, focusing on the understanding of values, attitudes, or risk perceptions; environmental resources studies, focusing on the integration of social dimensions to improve management actions; environmental philosophy and history, focusing on disciplinary, conceptual, or ethical issues; and environmental decision making, focusing on decision analysis process and risk assessment. Simultaneously, we took the social-oriented studies ($N = 124$) out of the sample of total biological invasion studies ($N = 15,915$) and used the Mann-Whitney U test to compare the trend in publications per year between the total for the field and those including social dimensions.

We identified 25 articles that described 28 science-society conflicts in invasive species research or management. We interpreted these under the rubric of the integrated CHT-risk perception framework (Fig. 1), exploring the underlying cognitive level at which disputes occurred. We categorized each dispute according to the cognitive structure that mainly explained the source of

Table 1. Typology of human values of nature, based on Kellert (1993, 2009).

<i>Value</i>	<i>Definition</i>
Aesthetic	Physical attraction and appeal of nature
Dominionistic	Mastery and control over nature
Humanistic	Emotional, spiritual, or symbolic affection for nature
Moralistic	Moral concern about the right and treatment of nature
Naturalistic	Exploration of nature and outdoor recreation
Negativistic	Fear or aversion toward nature
Scientific	Systematic and empirical study of nature
Utilitarian	Practical value or material benefit of nature

conflicts, even though we recognize that some cases could have multiple explanatory variables. Some of the articles referred to 2 or more case studies, which were assessed independently in the review. To avoid duplication, only the original reference was included when another paper also described the same issue. Cases were classified by conflict level (value based or perceptions based) and conflict type (specific values or heuristic rules). Although other value typologies exist (e.g., Stern & Dietz 1994; Rohan 2000), we used Kellert's (1993, 2009) classification, which is commonly used in environmental studies and describes 8 fundamental values that address different dimensions of human relationships with nature (Table 1).

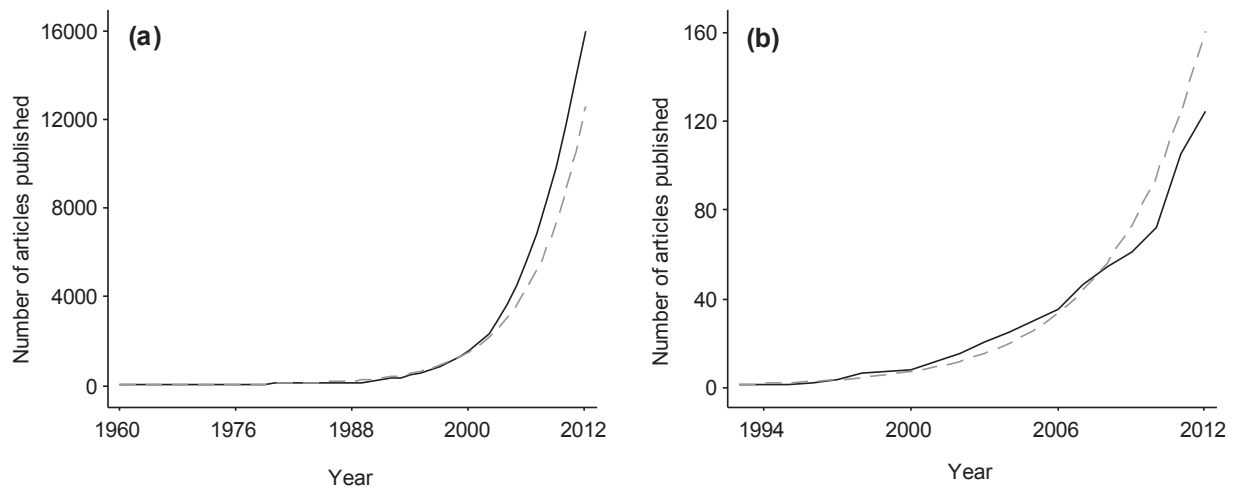


Figure 2. Year of publication of the articles analyzed in the review of peer-reviewed literature on biological invasions (solid line, published article trends; dotted line, fitted quadratic model) relative to (a) total publications on invasive species ($n = 15,593$) ($Yt = 2.09 * 1.194t^2$, MAPE = 29.0%) and (b) publications on invasive species that included social dimensions ($n = 124$) ($Yt = 0.83 * 1.301t^2$, MAPE = 22.2%) (Yt , function of t ; MAPE, mean absolute percent error). There is an order of magnitude difference in the y-axis scales. The full publication list for (b) is in Supporting Information.

Results

Bibliometric Trends

Through biological keywords, we found 15,915 papers on invasion biology, 124 of which incorporated social dimensions in the study or management of invasive species (<1% of the total). The number of all types of invasion biology publications increased greatly over the study period, but social-oriented publications ($N = 124$, median in 2010) were significantly more prevalent after 2000 relative to the total number of papers in the field (median was in 2008 of the 15,915 total) ($U = 125,542,719$, $P = 0.016$) (Fig. 2). Ninety-three percent of such studies were published since 2000.

Publications on the social dimensions of invasion biology have added new perspectives to the traditional and still dominant ecological focus of the sub-discipline. The largest number of articles dealt with environmental social science (44.5%), including the role of values, risk perceptions, attitudes, and behaviors toward invasive species. Environmental resource management (27.4%) was the second most prevalent category, which generally integrated social dimensions in management research. Environmental philosophy and history papers (17.7%) mainly aimed at reconciling discrepancies among perspectives on invasive species, and papers that focused on environmental decision making (10.4%) included multi-criteria decision analysis and risk assessment.

The recent emergence of social topics was distributed in the wide array of journals ($N = 69$). The majority of social research on invasive species was published in natural science journals; 19% of publications were from

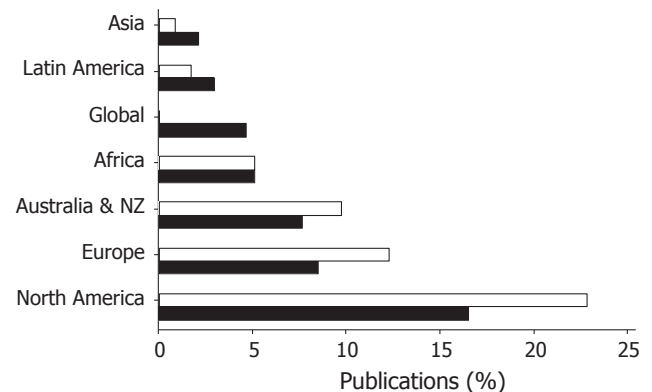


Figure 3. Geographic distribution of first author affiliation (white) and research location (black) for publications on the social dimensions of invasive species ($n = 124$ articles) (NZ, New Zealand).

journals categorized as social science in WOS. The most highly cited papers were those published in journals with an ecological or conservation biology focus, with the exception of *Geographical Review* and *Risk Analysis* (Table 2). Finally, the geographic distributions of authors and research locations showed a dominance of studies conceived of and carried out in the United States, Europe, and Australia (Fig. 3).

Conflicts in Invasive Species Management

We found 28 case studies describing invasive species conflicts. The majority (82%) of conflicts derived from value system disagreements, but clashes due to risk perceptions

Table 2. Journals that published the most cited papers in this review the social dimensions of biological invasions ($n = 124$).*

Journal	Total citations	Number of papers	Mean citations per paper
<i>Biological Conservation</i>	139	6	23.2
<i>Conservation Biology</i>	103	6	17.2
<i>Ecological Economics</i>	86	6	14.3
<i>Environmental Management</i>	78	11	7.1
<i>Risk Analysis</i>	49	2	24.5
<i>Frontiers in Ecology & the Environment</i>	44	2	22.0
<i>Environmental Science & Policy</i>	36	4	9.0
<i>Geographical Review</i>	34	2	17.0
<i>Natural Areas Journal</i>	31	2	15.5
<i>Diversity & Distributions</i>	29	2	14.5
<i>Biodiversity & Conservation</i>	25	3	8.3

*Only those with ≥ 2 papers were included. Journals are organized in descending order based on total number of citations.

Table 3. Articles describing potential conflicts in invasive species management ($n = 28$).

Conflict level	Value or heuristic rule	Species and reference
Value system	Utilitarian	Animal Zebra mussel (<i>Dreissena polymorpha</i>), Binimelis et al. 2007; salmonids (<i>Oncorhynchus tshawytscha</i> , <i>Salmo salar</i>), Soto et al. 2001; García de Leaniz et al. 2010
		Plant Black wattle (<i>Acacia mearnsii</i>), De Wit et al. 2001; orange wattle (<i>Acacia saligna</i>), Higgins et al. 1997; resin bush (<i>Euryops floribundus</i>), Shackleton & Gambiza 2008; buffel grass (<i>Cenchrus ciliaris</i>), Friedel et al. 2011; Marshall et al. 2011; hydrilla (<i>Hydrilla verticillata</i>), Binimelis et al. 2007
	Moralistic	Animal Cat (<i>Felis catus</i>), Clarke & Pacin 2002; deer (<i>Cervus elaphus</i> , <i>Axis porcinus</i>), Hall & Gill 2005; grey squirrel (<i>Sciurus carolinenses</i>), Barr et al. 2002; Bertolino & Genovesi 2003; Mute Swans (<i>Cygnus olor</i>), Perry & Perry 2008; wild horse (<i>Equus ferus</i>), Rikoon 2006; brown rats (<i>Rattus rattus</i> , <i>R. norvegicus</i>), Meech 2005
		Humanistic Animal wild boar (<i>Sus scrofa</i>), Maguire 2004 Plant Pine (<i>Pinus</i> spp.) and eucalyptus (<i>Eucalyptus</i> spp.), Van Wilgen 2012; box elder (<i>Acer negundo</i>), Foster & Sandberg 2004
	Naturalistic, dominionistic, aesthetic	Animal Feral pig (<i>S. scrofa</i>), Perry & Perry 2008; rainbow (<i>O. mykiss</i>) and brown trout (<i>S. trutta</i>), Quist & Hubert 2004; deer (<i>C. elaphus</i>), Hall & Gill 2005
		Negativistic Animal Cane toad (<i>Rhinella marina</i>), Shine & Doody 2011
	Risk perception	Evaluation of potential hazards
Lack of institutional trust Animal Emerald ash borer (<i>Agrilus planipennis</i>), Mackenzie & Larson 2010 Plant Water hyacinth (<i>Eichhornia</i> spp.), Evans et al. 2008		

were also identified (18%). We detected a specific set of values and heuristic mechanisms that helped explain how people understood and acted toward invasive species (Table 3). These categories may help in the understanding of the role of underlying cognitive structures in the management of invasive species conflicts, but a conflict can only arise if there are 2 or more values systems or risk perceptions that compete among scientists, managers, local communities, or different stakeholders. In this sense, the categories are not exclusive and multiple components can be found in particular case studies.

Conflicts Based on Value Systems

Utilitarian values refer to a primary interest in the direct use and economic value of nature. Some invasive species play a vital economic role, providing basic resources for industries and local communities. Contentious situations emerge when a resource traditionally provided by a native organism is threatened by an economically valuable exotic species. Conflicts can arise when utilitarian values apply to the invasive species itself or to the native species it has replaced. For example, non-native salmonids (e.g., *Salmo salar*, *S. trutta*) have caused utilitarian value clashes in the southern hemisphere. Originally introduced to New Zealand by British colonists, local Maori communities were concerned about their impacts to their native fisheries (García de Leaniz et al. 2010). In Chile, trout and salmon were first introduced in the early 1900s for sport fishing and later for aquaculture. In 1994–1995, heavy storms caused the accidental escape of >4,000,000 farmed salmon, which led to negative impacts and clashes with the native artisanal fishery (Soto et al. 2001; García de Leaniz et al. 2010). In Australia, some ranchers depend economically on non-native species such as buffel grass (*Cenchrus ciliaris*) (Friedel et al. 2011; Marshall et al. 2011). Conflicts between scientists or managers and farmers arise particularly in areas that are highly productive grasslands but also are highly valued for conservation, the implementation of which requires elimination of the invasive grasses (Friedel et al. 2011). Likewise, the management of invasive woody species in South Africa, such as *Acacia saligna*, *A. mearnsii*, and *Euryops floribundus*, has led to disputes between local communities and scientists and managers when control of the invasive trees interferes with wood availability for rural livelihoods (Higgins et al. 1997; De Wit et al. 2001; Shackleton & Gambiza 2008). Similar management conflicts have been described for the zebra mussels (*Dreissena polymorpha*) in Ebro River (Spain), where despite the fact that this mollusk's aggressive expansion has caused huge economic losses in water intake pipes and electric generating plants (Pimentel et al. 2005), local fishing associations have opposed management that may interfere with

their economic activities, such as marinas and fishing camps (Binimelis et al. 2007).

Moralistic values reflect ethical connections between human and non-human nature, generally expressed in the right of animals to live and not be abused. The control of invasive animals often involves culling, which is strongly rejected by some social organizations. Confrontations between animal rights organizations and government agencies have emerged particularly in the management of large or charismatic mammals, such as feral cats (*Felis catus*) (Clarke & Pacin 2002), deer (e.g., *Cervus elaphus*) (Hall & Gill 2005), and wild horses (*Equus ferus*) (Rikoon 2006). The debate centers on a basic value disagreement between those who consider these animals to be invasive and bad and those who regard them as individuals with intrinsic worth in themselves, regardless of origin or impacts (Perry & Perry 2008). In this way, feral horse and deer culling programs are frequently controversial (Hall & Gill 2005; Rikoon 2006), but even the eradication of black and brown rats (*Rattus rattus*, *R. norvegicus*) on Lundy Island (U.K.) was opposed by animal rights groups concerned about the use of anticoagulant poisons in rats and other species (Meech 2005). The ultimate consequences of these conflicts are clearly illustrated by the proposed eradication program for grey squirrels (*Sciurus carolinensis*) in Italy, which was contested in court by community organizations and subsequently cancelled because the delay in action eventually made the project unviable (Barr et al. 2002; Bertolino & Genovesi 2003).

Humanistic values can be embodied in invasive species that hold important cultural or spiritual values for some people when emotional relationships are formed (Kellert 2009). For example, in northern Australia spiritual associations exist between local communities and invasive non-native animals, including camels (*Camelus dromedaries*), horses (*Equus caballus*), and water buffalos (*Bubalus bubalis*) (Robinson et al. 2005; Vaarzon-Morel 2010). Social conflicts arise when invasive species management interferes with local or regional identities based on these new socio-ecological species assemblages. In Hawaii, local communities have strenuously opposed invasive pig eradication (*Sus scrofa*) because pig hunting is part of traditional Hawaiian lifestyles to celebrate weddings and funerals (Maguire 2004). Likewise, city green space management in Toronto (Canada) illustrates such value discrepancies in a modern urban context; some residents attach emotional and historical values to non-native trees that are often removed in native landscape restoration programs (Foster & Sandberg 2004). These conflicts were also described for the removal of invasive pine (*Pinus* spp.) and eucalyptus (*Eucalyptus* spp.) trees in South Africa (Van Wilgen 2012).

Naturalistic, dominionistic, and aesthetic values are grouped here and together represent the capacity of

nature to evoke satisfaction in humans through direct experiences, physical appeal, or control over nature. In the context of invasive species, these values normally emerged in outdoor recreation activities, such as hunting or fishing. For example, in the United States, the management of non-native brook trout (*Salvelinus fontinalis*) and brown trout (*S. trutta*) has caused concerns among local anglers who do not support restrictive regulations that reduce fishing opportunities (Quist & Hubert 2004). Although these situations are also linked with utilitarian values, the driving point of contention appeared not to be the potential economic impacts but rather the emotional limitation associated with the restriction of fishing as a cultural and recreational activity. Similar tensions exist in the control of invasive pigs in parts of the continental United States. Originally introduced for hunting and food, extensive cultural and recreation hunting activities are now centered around these feral pig populations (Perry & Perry 2008). Despite animal rights organizations also being concerned about culling practices, hunting associations are particularly well organized to prevent eradication of feral pigs for recreational purposes, and the literature showed that deer management in Australia faces many of the same issues (Hall & Gill 2005).

Negativistic values were not commonly encountered as a source of conflict in the management of invasive species. However, disagreements based on this value were described for cane toads (*Rhinella marina*) in Australia (Shine & Doody 2011). Authors suggested that people's natural aversion toward this invasive species had mobilized local communities to develop their own management actions, expending >AU\$20 million. Nevertheless, these programs were not supported by scientists or managers, and there is no evidence that the communities' activities reduced the toad's populations. Therefore, disagreements between community organizations and scientific research groups about ecological impacts and how to control cane toads have impeded progress in this area because successful management actions require consensus and general public support in concert with effective actions.

Conflicts Based on Risk Perceptions

Social groups perceived and evaluated the hazard of invasive species differently in a range of situations, and these differing interpretations of hazards constituted a secondary source of conflict. Disagreements can be enhanced by high levels of uncertainty in predicting invasion rates, potential negative impacts, and effectiveness of eradication actions (Maguire 2004; Liu et al. 2011). As stated above, risk perceptions are strongly influenced by value orientations. For example, in the management of weeds through pesticide application, experts' risk

assessments may not overlap with other stakeholders' evaluations. In particular, local communities are greatly concerned about the health hazards and secondary environmental consequences of spreading pesticides (Van Tassell et al. 1999). Norgaard (2007) presented a well-documented case study that illustrates the underlying issues involved. In 1997, the spotted knapweed (*Centaurea maculosa*), a highly invasive plant, was found along the Clearwater River in California (U.S.A.). The state's agriculture department proposed an intense areal herbicide treatment, which was strongly opposed by local communities and the Karuk Tribe. In this case, the opposing evaluations by the different actors of potential hazards were based on long-standing differences in the perceptions of local communities, indigenous groups, and the U.S. Forest Service.

As described above, exotic salmonids have been a common cause of value conflicts in the southern hemisphere. At the same time, though, even in the northern hemisphere, the salmon farming industry in Ireland was at odds with traditional salmon producers due to differential risk perceptions about the potential of new introduced genetic strains of salmon to affect native stock (Stokes et al. 2006). Similarly, in the Norris Reservoir (Tennessee, U.S.A.), different perceptions of the impacts of introduced striped bass (*Morone saxatilis*) on native fishes have been a cause of polarization in the local fishing community (Churchill et al. 2002).

We also found that conflicts arose when decision-making processes lacked participation and transparency, a situation that led local communities to mistrust government agencies. These conflicts were related to different evaluations of potential hazards, and lack of confidence emerged as a driving factor. Trust acquired particular relevance when management initiatives necessitated rapid responses and decision makers could not spend long periods building consensus (Caplat & Coutts 2011). Mackenzie and Larson (2010) describe a case arising from a rapid response to control the emerald ash borer (*Agrilus planipennis*), an invasive beetle detected in southern Ontario (Canada) in 2002. Management included cutting the healthy trees in the vicinity of the infected area, which was strongly criticized by landowners. These authors concluded that a lack of personal and institutional trust was at the core of the public's opposition. A lack of institutional trust also affected the management of invasive water hyacinths (*Eichhornia crassipes*) in Florida (U.S.A.). For years, use of herbicides had been promoted against the wishes of local communities, and local residents lost faith in environmental managers and began to obstruct their conservation actions directly (Evans et al. 2008). Opposition to the control of another invasive aquatic plant (*Hydrilla verticillata*) in Guatemala arose in a similar context (Monterroso et al. 2011).

Discussion

Integrated Socio-Ecological Research on Invasive Species

The academic treatment of social dimensions in biological invasion research and management is mostly linked to ecological and conservation-oriented approaches and journals. We found that in general the integration of social dimensions to invasive species research is scarce, relative to the field's overall productivity. Nevertheless, our results suggest that interest and understanding of social approaches are increasing and maturing and that studies are beginning to lead to a conception of biological invasions as a socio-ecological phenomenon. We observed in the literature an incipient consolidation of the importance of treating the social aspects related to invasive species research and management in a wide range of journals and for a wide range of taxonomic groups and geographical regions.

Similarly, in a recent study of Patagonian invasion biology publications and researchers, Anderson and Valenzuela (2014) found a gap between what scientists state are their research priorities (frequently including social, policy, and management dimensions) and their actual research output (weighted toward ecological studies). Two potential scenarios are offered to explain this discrepancy: a time lag could exist between study design and publication, meaning that articles reflected an antiquated disciplinary mentality focused on the invasive species' autecology and impacts or researchers currently lack scientific evaluation and funding structures that facilitate or allow them to fulfill their own (and society's) priorities to conduct applied and socially relevant endeavors, rather than theoretical studies.

Confronting or Avoiding Conflicts in Invasive Species Management

Conflicts surrounding environmental management have been common and well reported since at least the 1960s (Ferreiro et al. 2013). A wide range of contentious situations arise around biodiversity conservation in particular (White & Ward 2010). Often typified by human-wildlife conflicts, these occur when 2 or more parties strongly disagree over conservation objectives. Essentially, however, these are mostly human-human conflicts that are triggered by social factors (Redpath et al. 2013). With this review, we have identified and distinguished some of the social conflicts involved in invasive species management. In our integrated conceptual framework for the assessment and analysis of social conflicts surrounding invasive species management, values systems and risk perceptions are understood as the fundamental basis of discrepancies among communities, decision makers, and scientists.

Other disciplinary approaches also have developed theoretical structures or practical strategies to address the

social dimensions of nature conservation (e.g., Gobster & Hull 2000). These approaches could contribute to understanding and confronting the inherent complexity of relationships between the human and environmental dimensions of socio-ecological issues. For example, a person's concept of nature, including species that are currently considered invasive, depends on context, and nature can be understood as a socio-political struggle in which a diverse array of people negotiate their ecological practices and institutions. In this line, concepts of environmental justice, democracy, and participation may also become central in the anticipation, resolution, and avoidance of socio-ecological conflicts. Yet, a better understanding of the underlying causes and levels of conflict in specific instances and of the general trends in the pattern of conflict can inform more effective dialogue, research, and action related to invasive species.

Overall, contentious situations largely originated from differing viewpoints based on utilitarian, moralistic, humanistic, or naturalistic values. In addition, though, risk perceptions also generated clashes; these clashes mainly derived from differences in the way various social actors evaluate the potential hazards of invasive species and from distrust of decision makers or institutions. Understanding the root of the conflict should allow the identification of more effective management actions and reconcile tensions before they become entrenched, unmanageable, and destructive. We devised specific recommendations by which systematic decision-making methodologies can be used to provide insights into dealing with issues related to value-based conflicts and with disagreements based on differences in risk perceptions. Nevertheless, real problems generally include a complex combination of case-specific particularities that simultaneously encompass values, perceptions, and institutional issues. Therefore, recommendations must include recognition of the singularity of each situation.

Structured Decision Making

Value-based conflicts are inherently difficult to resolve. Decision makers have to reconcile discrepancies in stakeholders' fundamental tenets, which individuals are usually reluctant to sacrifice or trade off (Baron & Spranca 1997). The question, then, is how to incorporate this plurality of environmental values into an effective management decision-making process (Perry & Perry 2008), particularly in scenarios where uncertainties are an important factor to consider. Structured decision making provides a multi-criteria decision analysis process that has been applied in invasive species management (Cook & Proctor 2007; Liu et al. 2011; Liu et al. 2012). This method is characterized as a collaborative and participatory process that combines analytical tools from decision

sciences and applied ecology with conceptual and theoretical frameworks from human judgment and cognitive psychology (Gregory et al. 2012).

Succinctly, structured decision making promotes the identification and recognition of each party's fundamental objectives, which in turn are related to ecological models and management alternatives to provide acceptable and meaningful outcomes for decision makers and other stakeholders (Maguire 2004). During the process, decision makers analyze consequences and alternatives according to objectives and explore well-informed and transparent solutions. Structured decision making helps minimize contentious situations by clarifying stakeholders' beliefs and exploring consensus solutions despite differences; thus, it facilitates negotiation and participation among stakeholders (Estévez et al. 2013).

On broader philosophical and epistemological levels, these approaches help in the identification, integration, and validation of a diversity of world views, which are posited as prerequisites to creating both sustainable and just societies (Leff 2010). Furthermore, these approaches account for and reconcile the power relationships that have historically silenced the voices of certain portions of society, even within science itself (De Sousa Santos 2006), and that have led to ineffective, inappropriate, or unethical management solutions.

Risk Communication and Trust Building

For the management of invasive species, risk-perception-based conflicts are mainly the result of differential interpretations of actual or potential hazards, even when stakeholders may share fundamental values or agree on specific management objectives. In these situations, decision makers require strategies with which to effectively communicate about risks and with which to exchange relevant information and opinions between experts and other stakeholders (Burgman 2005). Risk communication is a complex process, and its complexity hampers the development of definitive risk communication guides (Bier 2001). Despite these differences, good practices for risk communication have been proposed. Generally, they recognize uncertainties inherent in management and involve stakeholders in the identification and communication of risks, practices that represent core communication principles that promote convergence and understanding among stakeholders (Sellnow et al. 2009).

Mistrust between stakeholders and decision makers was another clear source of conflict in invasive species management. Building trust and encouraging participation and dialogue are crucial components of successful biodiversity management (Young et al. 2010). Generally, levels of trust can be increased by open and fair participatory management processes (Gilmour et al. 2013). Mackenzie and Larson (2010) likewise conclude that

developing transparent decision-making processes for invasive species management, based on fairness and inclusiveness, could promote confidence among stakeholders who may not trust decision makers but who may trust the process itself. On the basis of previous invasive species management experiences, participatory methods have been developed that reduce inter-organizational contention and ultimately help stakeholders find common management objectives.

Participatory approaches have been successful in several scenarios (e.g., Friedel et al. 2011; Monterroso et al. 2011; Ford-Thompson et al. 2012), but important questions remain open. Fundamental disagreements about management actions may remain even after the participation process has been developed. In situations without clear solutions (e.g., ideological or political based disputes), taking into account the problem's social dimensions is even more important because technical and scientific information alone cannot resolve such issues

Here, we showed that scientists and managers can be at odds with communities based on different value systems or risk perceptions, which limits or even curtails invasive species management initiatives. On the basis of the research trends and causes of conflicts we identified, we suggest that situations of contentious invasive species management can be ameliorated by identifying the cognitive level of the conflict through the use of strategies such as structured decision making and risk communication. The study and management of invasive species is faced with new challenges related to the societal demands for stakeholder participation in decision making. Scientists and managers, therefore, must adapt their strategies to these new socio-ecological scenarios that involve conceptual, practical, and ethical considerations.

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Supporting Information

The full list of publications included in the analyses is available online (Appendix S1). The authors are solely responsible for the content and functionality of these

materials. Queries (other than absence of the material) should be directed to the corresponding author.

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