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Expert opinion on extinction risk and climate change adaptation for biodiversity

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Abstract

Despite projections of biodiversity loss and proposed adaptations to climate change, few data exist on the feasibility and effectiveness of adaptation strategies in minimizing biodiversity loss. Given the urgent need for action, scientific experts can fill critical information gaps by providing rapid and discerning risk assessment. A survey of 2,329 biodiversity experts projects, on average, that 9.5% of species will become extinct due to climate change within the next 100 years. This average projection is low relative to previously published values but substantial in absolute terms, because it amounts to a loss of hundreds of thousands of species over the next century. The average projection increases to 21% when experts are asked to estimate the percentage of species that will become extinct within the next 100 years due to climate change in combination with other causes. More than three-quarters of respondents reported being uncertain about their extinction estimates. A majority of experts preferred protected areas or corridors to reduce extinction risk but identified *ex situ* conservation and no intervention as the most feasible strategies. Experts also suggest that managed relocation of species, a particular adaptation strategy, is justifiable and effective in some situations but not others. Justifiable circumstances include the prevention of species extinction and overcoming human-made barriers to dispersal, and while experts are divided on the potential effectiveness of managed relocation for most taxonomic groups, higher percentages predict it effective for woody plants, terrestrial insects, and mammals. Most experts are open to the potential benefits of managed relocation but are concerned about unintended harmful consequences, particularly putting non-target species at risk of extinction. On balance, published biodiversity scientists feel that managed relocation, despite controversy about it, can be part of the conservation adaptation portfolio.

Introduction

Research published in the last 20 years shows that species and ecosystems are responding to modern climate change. Many species are exhibiting changes in their phenology, geographic distribution, or physiology (Gordo and Sanz, 2010; Chen et al., 2011). Others are experiencing widespread population declines as well as natural and artificial restrictions on dispersal. As climate continues to change due to past, present, and future greenhouse gas emissions, we know that the biotic changes observed so far represent a small preview of those to come. Moreover, the available research is just a fraction of the research needed to understand ecological responses to climate change and strategies for reducing negative impacts. Without such research, scholars, practitioners, and policymakers risk taking management action that may be either unhelpful or even counterproductive.

Some negative effects of climate change could potentially be managed and reduced through various "adaptation" strategies. Adaptation refers to interventions that humans might take to reduce vulnerability or partially undo the effects of climate change (McLachlan et al., 2007; Heller and Zavaleta, 2009; Lawler, 2009; Mawdsley, 2011). Adaptation includes intensified and redirected activities from the traditional conservation toolbox and new, sometimes controversial, activities designed specifically to address the problems posed by climate change (Hellmann et al., 2011; Schwartz et al., 2012).

Given the significant magnitude and speed of warming, the time for developing and testing adaptation strategies is short and current data on the feasibility and effectiveness of adaptation in reducing biodiversity losses is limited. Fortunately, a large body of knowledge relevant to adaptation—e.g., on the sensitivity of species to changing conditions and on the interaction of multiple stressors in the environment—does exist in the ecological literature and in the expertise of research scientists. These experts can fill critical information gaps by using existing knowledge to provide rapid and discerning risk assessment. For example, experts may interpret published estimates in light of their simplifying assumptions and high uncertainty, as well as other data, to assess risk. While data remain limited, the collective judgment of experts can be a temporary and informative way to set research priorities, guide policy development, and avoid harmful missteps (e.g., Donlan et al., 2010; Martin et al., 2012).

To reveal and quantify expert opinion on the risk to biodiversity from climate change and the viability of various strategies of climate change adaptation, we surveyed individuals who possess a high degree of expertise related to the environment and biodiversity. Respondents were asked questions about projected global climate change, projected impacts of climate change on biodiversity, and opinions about the advantages and disadvantages of adaptation strategies designed to minimize those impacts. We also asked experts about a particular novel adaptation strategy called managed relocation (or assisted migration, assisted colonization). Managed relocation refers to the purposeful transporting of species outside their known historic distributions to new regions as a strategy for minimizing losses of biodiversity and ecosystem services to climate change (Schwartz et al., 2012; Richardson et al., 2009). The strategy is controversial because it is untested, uncertainty surrounds both its potential effectiveness and unintended consequences (Gray et al., 2011), and it raises significant ethical dilemmas (Minteer and Collins, 2010).

Empirical tests of the effectiveness or harm of managed relocation efforts are rare. There is some very limited evidence that the managed relocation of some butterflies (*Melanargia galathea* and *Thymelicus sylvestris*) could work and be reasonably cost effective (Willis et al., 2009) and that the managed relocation of the southern rock lobster (*Jasus edwardsii*) could improve the yield and sustainability of the fishery and reduce its vulnerability to climate change (Green et al., 2010). There have also been experiments involving managed relocation in the forestry industry, horticultural planting, and botanic gardens. These studies are directed primarily to the feasibility of managed relocation but will not generate results for some time (McKinney et al., 2009; Van der Veken et al., 2008; Vitt et al., 2010). No experimental research has addressed the potential adverse impacts of managed relocation on recipient communities. The vast majority of the managed relocation literature relies upon general theory and discussion without quantifying the issues, benefits, or risks of relocation, using direct or indirect assessment methods (but see McDonald-Madden et al., 2011; Mueller and Hellman, 2008). As managed relocation is currently being pursued by various groups with no clear legal guidelines or constraints (Gray et al., 2011), some form of educated policy guidance is necessary (Schwartz et al., 2012).

Here, we explore one method of acquiring relevant information on the advisability of climate change adaptation strategies such as managed relocation. We conducted a survey of experts in fields of organismal biology and ecology, disciplines closely related to biotic responses to climate change. As biologists, these experts are competent to comment on the justifiability and potential effectiveness of wildlife adaptation strategies. The goal of the survey was to gain insight from scholars whose areas of expertise were highly relevant to urgent adaptation questions, to provide abundant insights into a new conservation dilemma. Survey data are not a substitute for field or laboratory measurements of actual species or ecosystems, of course, but they can be a useful alternative to guide research and policy when scientific data are limited and information is urgently required. In this paper, we provide quantitative assessments of the perceived risks of managed relocation, using an indirect method that draws upon collective scientific opinion. To our knowledge, it is the first study of expert opinion about ecological issues or climate change that achieves a large sample from a well-defined population of experts.

Methods

Our target population (i.e., the population about whom we generalize our findings) was the world's leading environmental biologists. These individuals are best positioned to understand the distribution and abundance of biodiversity and how it responds to changes in the environment, including climate change (Javeline et al., 2013). They are not the only experts or key stakeholders in natural resource management, and not all members of the target population have published on or studied managed relocation, but they have highly relevant expertise in organismal biology or ecology.

Survey design

To represent this target population, we surveyed scientists who published in the top quartile of ecology, evolution, and conservation biology journals. Specifically, we used the "Journal Citation Reports" published by the Institute for Scientific Information (now Thomson Reuters) to determine which journals fell in the top quartile. We then compiled a list of corresponding authors of articles published between August 2003 and July 2008. (For a list of journals, see online supplement. For more details about the sampling frame and other aspects of survey design, see Javeline and Shufeldt, 2013.)

Our list of published scientists included 15,479 corresponding authors, and we chose a census approach, inviting all to participate in a web-based survey. We selected the corresponding author because she/he is the scientist designated to represent the article and therefore should be knowledgeable about the subject matter.

Respondents were sent email invitations, delivered in batches between October 19, 2010, and May 6, 2011 to reduce load on the server hosting the survey. To maximize participation in the survey and minimize bias, we employed incentives and reminders, and we systematically attempted to convert respondents who refused to take the survey. We informed the scientists of the exclusiveness of the target population and the importance of their particular opinions as members of this target population. We also offered a professional incentive in the form of early opportunity to examine the survey results. Respondents were sent six reminders over the course of eight weeks. Respondents who emailed to say they would not participate (220) all received a personalized reply attempting to convert the refusal by acknowledging the legitimacy of their concerns and emphasizing the value of their expertise.

Our survey received approval for the use of human subjects by the University of Notre Dame's Institutional Review Board. A statement about confidentiality, the voluntary nature of survey participation, and the absence of risk associated with participation was included as part of an informed consent document.

Survey questions

The survey was composed of six modules of questions: professional demographics, climate change, biotic responses to climate change, invasive species, managed relocation, and personal demographics (see online supplement Text S2 for full survey). For the managed relocation module, many questions focused on the justifiability or potential effectiveness of managed relocation as a strategy to adapt to climate change. The literature on expert elicitation recommends assessing experts' degree of confidence around their judgments (Teigen and Jorgensen 2005; Speirs-Bridge et al., 2010; Martin et al., 2012). Consistent with this recommendation, respondents were often asked to estimate the certainty of their estimates with a four-point scale from "very certain" to "not at all certain."

In terms of justifiability, respondents were asked to rate managed relocation as justifiable or not justifiable for specific objectives (to prevent species extinction, prevent loss of unique genotypes or ecotypes, or preserve or enable ecosystem function). They also rated managed relocation depending on different unintended consequences (putting non-target species at risk of extinction, impairing ecosystem function, causing no ecological harm, or having unknown consequences) and different information requirements (specific scientific data indicating that the action would prevent extinction of the target species, broad consensus among experts that the action would prevent extinction of the target species, or stakeholders strongly arguing that the action would prevent extinction of the target species). These objectives, unintended consequences, and information requirements were presented in different combinations (e.g., Is managed relocation justifiable or not if it prevents extinction of the target species but has the possible unintended consequence of putting non-target species at risk of extinction?; Table 1).

In terms of the perceived effectiveness of managed relocation, respondents were asked about the groups of organisms with which they work most closely and how effective the introduction of a single population of these species would be in achieving the goal of poleward (or upward) range expansion (Table 2).

All respondents, regardless of taxonomic expertise, were asked about the potential for managed relocation of species from thirteen different taxonomic groups to cause unintended harm. (Taxonomic experts and other experts had similar distributions of answers to these questions (data not shown).) On a four-point scale from "very likely" to "not at all likely," respondents reported how likely it is that managed relocation of a single species to multiple locales would put non-target species at risk of extinction, impair ecosystem services, or cause loss of unique genotypes. See Table 3 for the wording of questions about unintended harm and response categories.

In addition to abstract questions about managed relocation, we asked respondents about three specific cases: forest replanting in Ontario of genotypes or species from farther south for timber production; managed relocation of Mitchell's satyr, a federally endangered subspecies of butterfly found in less than two-dozen peatlands in Michigan and northern Indiana; and managed relocation of zooxanthellae, the algal symbionts that provide coral with up to 90% of their energy. Questions asked in the case studies were similar to the more abstract questions above and asked about the justifiability, perceived effectiveness, and potential benefits and harm in each case. For the questions about justifiability in the case studies, the response categories were: "very justifiable," "somewhat justifiable," "not very justifiable," and "not at all justifiable." For the questions about potential ramifications of managed relocation, the question asked how beneficial or detrimental the ecological impacts associated with managed relocation would be, with response categories of: "very beneficial," "somewhat beneficial," "equally beneficial and detrimental," "somewhat detrimental," and "no detectable impact."

Table 1. Perceived justifiability of managed relocation, percentage of respondents answering "justifiable" over "not justifiable" (dichotomous response set) in descending order (*N* = 2,329)

Circumstance under which managed relocation would be justifiable or not	Justifiable (%)
To overcome a human-made barrier like urban or agricultural region and unlikely to cause any ecological harm	92.3
Specific scientific data indicates that action would prevent extinction of target species and unlikely to cause any ecological harm	89.4
To prevent species extinction and unlikely to cause any ecological harm	88.3
Broad consensus among experts is that action would prevent extinction of target species and unlikely to cause any ecological harm	84.3
To preserve or enable ecosystem function and unlikely to cause any ecological harm	79.8
To prevent loss of unique genotypes or ecotypes and unlikely to cause any ecological harm	77.3
To overcome its own limited speed of dispersal and unlikely to cause any ecological harm	72.8
To overcome a natural dispersal barrier and unlikely to cause any ecological harm	70.2
To prevent species extinction and unintended consequence is putting non-target species at risk of extinction	63.6
To prevent species extinction and unintended consequence is impairing ecosystem services	57.4
To prevent species extinction and consequences are unknown	55.8
To overcome a human-made barrier like urban or agricultural region and consequences are unknown	55.6
To preserve or enable ecosystem function and unintended consequence is putting non-target species at risk of extinction	55.4
To overcome a human-made barrier like urban or agricultural region and unintended consequence is putting non-target species at risk of extinction	55.4
Specific scientific data indicates that action would prevent extinction of target species and consequences are unknown	54.1
Specific scientific data indicates that action would prevent extinction of target species and unintended consequence is putting non-target species at risk of extinction	50.0
Stakeholders strongly argue that action would prevent extinction of target species and unlikely to cause any ecological harm	47.9
To prevent loss of unique genotypes or ecotypes and unintended consequence is putting non-target species at risk of extinction	41.8
Broad consensus among experts is that action would prevent extinction of target species and unintended consequence is putting non-target species at risk of extinction	41.8
Broad consensus among experts is that action would prevent extinction of target species and consequences are unknown	40.7
To preserve or enable ecosystem function and consequences are unknown	37.6
To prevent loss of unique genotypes or ecotypes and unintended consequence is impairing ecosystem services	31.2
To overcome its own limited speed of dispersal and consequences are unknown	30.1
To overcome its own limited speed of dispersal and unintended consequence is putting non-target species at risk of extinction	29.2
To overcome a natural dispersal barrier and consequences are unknown	26.8
To prevent loss of unique genotypes or ecotypes and consequences are unknown	26.2
To overcome a natural dispersal barrier and unintended consequence is putting non-target species at risk of extinction	25.0
Stakeholders strongly argue that action would prevent extinction of target species and consequences are unknown	13.8
Stakeholders strongly argue that action would prevent extinction of target species and unintended consequence is putting non-target species at risk of extinction	13.2

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"Don't know" was not offered as a response category, but respondents were allowed to skip questions after bypassing a single prompt to ensure that the nonresponse was purposeful. Many survey questions involved categorical responses (e.g., Tables 1, 2, and 3), but some questions asked respondents to provide a numeric response, providing continuously distributed data. Continuous response data are reported as a mean and standard deviation, and the distribution of response values are given.

Survey responses

Our response rate was 15 percent or 2,329 respondents who completed the survey of the initial 15,479, a rate consistent with past studies and challenges associated with declining response rates for web surveys (Kiesler and Sproull, 1986; Cook et al., 2000; Dillman, 2000; Sheehan, 2001; Kaplowitz et al., 2004; Doran and Zimmerman, 2009). The response rate is encouraging when considering the possibility of spam filtering,

Table 2. Perceived effectiveness of managed relocation, according to taxonomic specialists:

"In a previous question, you named [X] as groups of organisms with which you work most closely. Consider a managed relocation program to enable poleward (or upward) range expansion of a species in each group under climate change. In your view, how effective do you think that the introduction of a single population would be in achieving this goal –very effective, somewhat effective, not very effective, not at all effective?"

Taxonomic group	Very or somewhat effective (%)	*N*
Other terrestrial invertebrate	55.1	214
Insect vectors of disease	51.7	58
Woody plants	51.4	667
Ants, bees, and/or wasps	50.0	148
Mammals	49.5	551
Perennial plants	47.4	679
Fish	47.1	355
Freshwater invertebrates	46.2	201
Reptiles	45.2	199
Annual plants	44.5	407
Birds	42.7	512
Beetles	41.6	137
Butterflies and/or moths	41.0	185
Fungi	38.9	54
Microorganisms	37.9	166
Amphibians	35.7	213
Marine invertebrates	33.5	191
Spiders	32.6	43

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vacations, the sampling frame of scientists who often conduct field work, and the length of the survey, which took on average 51 minutes to complete.

No independent data are available to analyze nonresponse, but 220 nonrespondents did correspond with us, giving some insight into reasons why individuals may not respond to the survey. Most of these nonrespondents (170) said that they did not have sufficient expertise in wildlife adaptation. Although the target sample is defined as having potentially relevant opinions because they publish in directly relevant fields, these nonrespondents interpreted expertise more precisely. If this reason applies to other nonrespondents, individuals with less experience with the survey topic may be less likely to respond. Less knowledgeable individuals may be under-represented in the sample. The results reported below are unlikely to be significantly biased because the level of expertise (as reflected in self-assessed knowledge about climate change, biotic responses to climate change, and invasive species and the number of publications on these topics) is unrelated to opinions about managed relocation.

We also verified the validity of our sample by asking how many of the respondent's publications addressed biotic responses to climate change, a key factor for formulating opinions on managed relocation. Although the study of biotic responses to climate change is a new subfield, 59% of respondents published at least one article on it, and 43% of respondents published two or more.

All respondents, by virtue of landing in our sampling frame as corresponding authors in leading journals, possess some kind of scientific expertise. Fifty-eight percent are professors at research universities or teaching colleges, and the remaining are mostly postdoctoral researchers (19%), research personnel at government or non-government agencies (17%), or students (2%). The vast majority have Ph.D.s (95%) and are male (75%), with 76% earning their highest degree between 1991 and 2010. Respondents reside in the United States (41%), Canada (7%), Australia (6%), the United Kingdom (6%), and 62 other countries.

Respondents characterize their expertise as ecology (58%), evolutionary biology (25%), and conservation biology (17%) and the biological level of their expertise as populations (36%), communities (24%), organisms (20%), and ecosystems (16%), with 4% having expertise that they characterize as non-biological, including social science, landscape ecology, policy, or statistics. Respondents work on many kinds of organisms and ecosystems in all regions of Earth. The largest groups of respondents work in North America (53%), in forest (44%) or grassland (22%) ecosystems, and on perennial plants (30%), woody plants (29%), mammals (24%), birds (22%), annual plants (18%), and fish (16%).

Table 3. Perceived unintended harmful consequences of managed relocation (*N* = 2,329)

How likely is it that a managed relocation of a single species to multiple locales will…			
	Very or somewhat likely (%)*		
Taxonomic group	Put non-target species at risk of extinction	Impair ecosystem services	Cause loss of unique genotypes
Pathogens	79.0	72.5	66.6
Small mammals	71.3	55.0	56.3
Freshwater invertebrates	69.5	61.0	58.3
Insects	69.2	66.6	59.5
Large mammals	64.6	59.2	53.2
Herbaceous plants	63.5	63.2	60.7
Other terrestrial invertebrates	60.3	53.1	53.2
Miccroorganisms	60.2	60.6	56.9
Marine invertebrates	59.4	54.1	52.2
Reptiles	54.8	33.9	49.0
Woody plants	54.2	61.5	52.4
Amphibians	52.2	31.3	48.6
Birds	47.6	31.7	44.7

*Other response options were "not very likely" and "not at all likely."

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Results

Scientists in our survey estimate, on average, that 9.5% of species will be committed to extinction due to climate change within the next 100 years. The distribution of extinction estimates is shown in Fig. 1. It is strongly right-skewed with 53% of respondents expecting that fewer than 10% of non-microbial species will be driven to extinction due to climate change. Many fewer respondents (8%) estimate that rates of extinction will be higher than 20% of non-microbial taxa. These estimates are low relative to some previously published estimates that, depending on assumptions about climate change and species movement, projected 9–52% of species would be committed to extinction by 2050 (Thomas et al., 2004; Fischlin et al., 2007; but also see Maclean and Wilson, 2011). The average estimate of species extinction is higher (21%) when scientists consider the combined effect of climate change and other causes within the next 100 years.

The estimates are also uncertain: Three-quarters of respondents said they were not very certain (48%) or not at all certain (29%) about their estimates of extinction risk due to climate change and not very certain (45%) or not at all certain (25%) about their estimates for the combined risk of climate and other causes. Our survey instrument did not ask respondents why their estimates of extinction risk were higher or lower than published estimates, but respondents estimated on average that only 14% of species that would "otherwise be threatened by climate change … will escape extinction by evolutionary adaptation."

Responses about which adaptation actions are suitable to reduce extinction risk from climate change differed. In response to the question, "In the case of a species that is immediately threatened with extinction by climate change, which is most **preferable**, no intervention, expand protected areas, establish corridors, managed relocation, or *ex situ* conservation site (e.g., preservation in a zoo, seed bank, or botanic garden)?," respondents ranked as their preferred strategy expanding protected areas (41%), followed by the establishment of corridors (30%), *ex situ* conservation (15%), managed relocation (12%), and no intervention (2%). In response to the

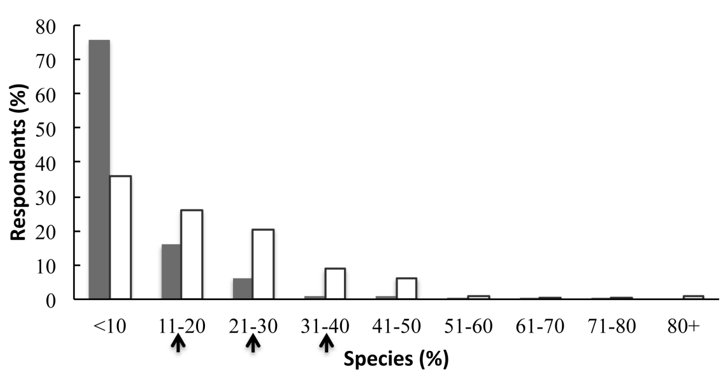

Figure 1

Distribution of responses to key survey questions.

Respondents were asked "In your opinion, what percentage of non-microbial species will be committed to extinction solely due to climate change in the absence of other causes within the next 100 years?" (gray bars) and "In your opinion, what percentage of non-microbial species will be committed to extinction due to a combined effect of climate change and other causes within the next 100 years?" (white bars). For gray bars, the mean response was 9.5% (s.d. 9.3); for the white bars, the mean response was 21% (s.d. 15.6). For comparison, the percentages of species from (Sheehan, 2001) expected to go extinct under a low (18%), medium (24%), and high (35%) scenario of climate warming by 2050 are marked on the x-axis. Several other studies (Pereira et al., 2010), each examining a different taxonomic group, predict a wide range of extinction, from a low of <1% bird species (Jetz et al., 2007) to ~40% of endemic plants and vertebrates (Malcolm et al., 2006).

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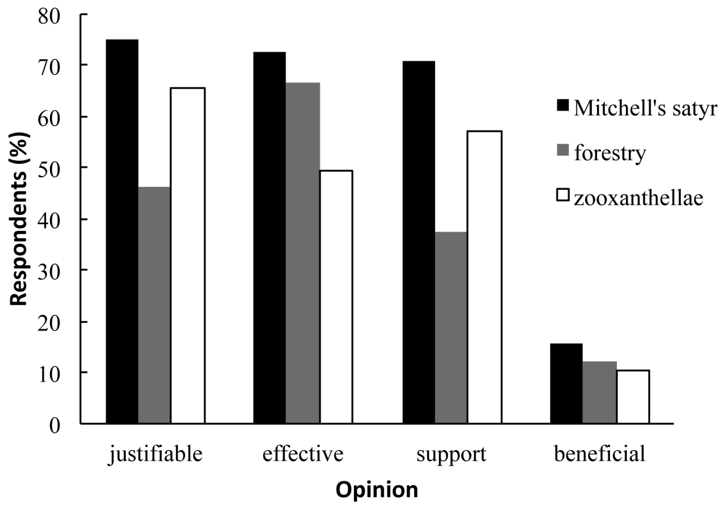

Figure 2

Expert opinion on the three hypothetical scenarios of managed relocation.

Respondents were asked about the Mitchell's satyr, a federally endangered subspecies of butterfly found in less than two-dozen peatlands in Michigan and northern Indiana; forest replanting for timber production using genotypes or species from farther south; and zooxanthellae, the algal symbionts of coral that appear to be temperature sensitive (Sotka and Thacker, 2005). Percentage of respondents saying (a) managed relocation in each case would be somewhat or very justifiable, (b) managed relocation would be somewhat or very effective at achieving its goal, (c) they are somewhat or very supportive of managed relocation, and (d) the ecological impacts of managed relocation would be somewhat or very beneficial compared to its detrimental impacts, N = 2,239 published environmental scientists. The questions in (a–c) included four response categories ranging from "very" to "not at all"; (d) included five response categories ranging from "very beneficial" to "very detrimental," with a middle alternative of "equally beneficial and detrimental" and a sixth alternative of "no detectable impact." The results show that scientific opinion on justifiability, potential effectiveness, potential benefits, and support for managed relocation varies depending upon the species and context in question.

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question, "In the case of a species that is immediately threatened with extinction by climate change, which is most **feasible**?," a minority of survey respondents selected *ex situ* conservation (35%), no intervention (21%), expanding protected areas (16%), managed relocation (16%), and establishing corridors (12%).

Regarding managed relocation in particular, expert opinion is context dependent. When asked about overall support for the strategy in a general sense with no named species or scenario, few respondents were pure proponents (7%) or pure opponents (9%), and most offered middling responses of either somewhat supportive (46%) or not very supportive (38%). Respondents considered the strategy justifiable in some circumstances but not others (Table 1). For example, experts were nearly unanimous (92%) in finding managed relocation very or somewhat justifiable if the goal were to overcome a human-made dispersal barrier such as an urban or agricultural region and if, simultaneously, the managed relocation was unlikely to cause any ecological harm (Table 1). Respondents were also nearly unanimous (87%) in *not* finding managed relocation very or somewhat justifiable where stakeholders strongly argue that the action would prevent extinction of a target species, but the unintended consequence would put non-target species at risk of extinction (Table 1).

As shown in Table 1, circumstances with the highest percentage of respondents finding managed relocation very or somewhat justifiable include: minimization of ecological harm, overcoming a human-made dispersal barrier, preventing species extinction, and specific scientific data that managed relocation would prevent species extinction. The circumstances with the lowest percentage of respondents finding managed relocation very or somewhat justifiable include: managed relocation programs that stakeholders argue would prevent extinction of the target species and those that put non-target species at risk of extinction. Experts hold moderate or divided views on the justifiability of other circumstances for managed relocation (preserving or enabling ecosystem functioning, preventing loss of unique genotypes or ecotypes, overcoming limited speed of dispersal, overcoming a natural dispersal barrier, and broad consensus among experts that the action would prevent extinction of the target species), and the assessments of justifiability seem driven more by other circumstances that are paired with these less consequential circumstances (Table 1).

Opinions about the justifiability of managed relocation were further examined with specific case studies (Fig. 2). A high percentage of respondents thought managed relocation would be somewhat or very justifiable in hypothetical cases about an endangered butterfly (56% somewhat justifiable, 19% very justifiable; black bars in Fig. 2) and temperature-sensitive symbionts of coral related to coral bleaching (50% somewhat justifiable, 15% very justifiable; white bars in Fig. 2), but respondents were divided on the third case about a tree species involved in timber production (41% somewhat justifiable, 5% very justifiable; gray bars in Fig. 2).

Respondents also indicated that the potential effectiveness of managed relocation at stemming biodiversity losses is variable and dependent on the species. According to experts in each of 18 taxonomic groups, managed relocation has the highest potential effectiveness (measured by the percentage of respondents saying managed relocation would be "very effective" or "somewhat effective") for woody plants; ants, bees, and/or wasps; other terrestrial invertebrates; and mammals. Only half of the specialists for these groups, however, assess managed relocation as potentially very or somewhat effective (Table 2). Respondents indicated that managed relocation has the lowest potential effectiveness for spiders, marine invertebrates, amphibians, microorganisms, and fungi (Table 2). When assessing specific cases, two of those managed relocation efforts (Mitchell's satyr and forestry) are seen as very or somewhat effective by a high percentage of respondents (73% and 67% respectively), while only 49% view managed relocation as effective in a third case (zooxanthellae) (Fig. 2).

According to surveyed experts, the potential for managed relocation to cause unintended harm depends on the species and the type of harm (Table 3). Respondents were asked: "In your opinion, for each taxonomic group below, how likely is it that managed relocation of a single species to multiple locales" will put non-target species at risk of extinction, impair ecosystem services, or cause the loss of unique genotypes. In regard to impairing ecosystem services or causing loss of unique genotypes, the smallest percentages of respondents (<34% and <50%, respectively) indicated that the managed relocation of birds, amphibians, and reptiles is likely to have these effects, and the highest percentages of respondents (>63% and >59%, respectively) indicated these effects are likely for the managed relocation of pathogens, herbaceous plants, and insects. There is more unified concern about the risk of putting non-target species at risk of extinction: the majority of those queried (>52%) say that managed relocation of every taxonomic group except birds is very or somewhat likely to put non-target species at risk, and a strong majority (>66%) express this concern for insects, freshwater invertebrates, small mammals, and pathogens.

All the above results are relatively similar if we disaggregate respondents by their professional demographics, such as place of employment, biological level of expertise, location of primary research, taxonomic specialty, or ecosystem specialty. These professional characteristics and areas of expertise seem unrelated to opinions about managed relocation.

Discussion

Given recent, possibly conservative, estimates of the number of species residing on Earth (Costello et al., 2013a, 2013b; Mace et al., 2005) a climate driven extinction estimate of ~ 10%—the level of likely extinction found in our survey and compatible with a recent estimate using red list data (Maclean and Wilson, 2011)—would mean the loss of hundreds of thousands of species. A large majority of respondents, however, were highly uncertain about their estimations of extinction risk. We do not know the reason for this uncertainty, but the literature is generally skeptical of the assumptions underlying extinction estimation (e.g., Fordham et al., 2012; Matias et al., 2014; Pearson et al., 2014).

Survey respondents were divided about which adaptation strategy would be most effective at combatting extinction risk from climate change, suggesting that no existing adaptation strategy offers an ideal course of action. Strategies that enable species to adjust to climate change on their own, using protected areas or corridors, appear to be favored by experts, but experts do not identify these strategies as particularly feasible. These responses are likely based on the fact that only 12% of land worldwide is set aside as protected, and large increases in protected land area seems unlikely given human population growth, urbanization, and agriculture (Chape et al., 2005; Gaston et al., 2008). Current protected areas could be traded for alternative ones that may be more effective under future conditions, but such trades have limited capacity to provide the necessary protection in the necessary places (Hole et al., 2011; Williams et al., 2013). Greater use could be made of *ex situ* conservation but expense and limited opportunity to maintain healthy breeding populations are significant impediments (Pritchard et al., 2012).

Managed relocation may or may not be a partial solution to the considerable problem of climate-induced extinction risk and other biodiversity losses, but environmental biologist are open to its benefits, especially in restricted circumstances. Experts feel that managed relocation is neither preferable nor more feasible in comparison to other adaptation strategies, but their support for it appears somewhat neutral (84% in the two middle categories of support for managed relocation overall). This neutrality may reflect the relative novelty of managed relocation as an adaptation strategy, and the measured opinion recorded here stands in strong contrast to the more polarized pro versus con debate that exists in the literature (Hoegh-Gulberg et al., 2008; Ricciardi and Simberloff, 2009; Klenk and Larson, 2013).

Probing questions about the circumstances that potentially justify managed relocation suggest that expert opinions about it are context dependent. Experts see it as justifiable and potentially effective in some cases, but they are concerned about unintended harmful consequences. A relatively high percentage of respondents justified the use of managed relocation when it is designed to prevent species extinction, overcomes a human-made dispersal barrier, minimizes ecological harm, and responds to specific scientific data. Fewer respondents justified managed relocation to preserve or enable ecosystem functioning, prevent loss of genetic diversity, or overcome natural dispersal barriers, suggesting that managed relocation policy consider these circumstances but give them a lower priority. Very few respondents justified managed relocation if it would put non-target species at risk of extinction or be based on stakeholder arguments about preventing the extinction of the target species, suggesting that managed relocation policy involve careful consideration of the possibility of negative unintended consequences and the rigor of data used as justification (Richardson et al., 2009; Schwartz and Martin, 2013).

If principles, rules, or legal guidelines were to be developed to guide managed relocation, our results suggest that they should be detailed and specific to particular species and situations. No single guideline will apply to all species, ecosystems, and circumstances, because scientists identify different risks and rewards in different contexts. For example, respondents were divided on the justifiability of a managed relocation program for timber production, but a majority thought such a program would nevertheless be effective. Conversely, respondents were divided on the potential effectiveness of a managed relocation program for coral symbionts, but a majority thought such a program was justifiable. Similarly, respondents evaluated broad taxonomic groups differently in terms of effectiveness and likelihood of causing harmful side effects. Invertebrates, for example, received among the highest and lowest ratings for the potential effectiveness of managed relocation, showing either taxonomic resolution of expertise or, more likely, considerable uncertainty about managed relocation in general. Concern about the side effects of managed relocation is greatest for insects, freshwater invertebrates, small mammals, and pathogens and lowest for birds.

Based on these survey results, we suggest that managed relocation guidelines be situation-specific, as compatible with the species-specific adaptation strategies recommended in the U.S. government's first document on wildlife adaptation (National Fish, Wildlife, and Plants Climate Adaptation Strategy, 2012). This recommendation could be implemented by soliciting expert opinion in particular cases, and we recommend using the tools of survey research to measure expert opinion systematically. The moderate response to our overall support question about managed relocation also suggests that general questions about managed relocation are less useful for decision-makers than questions targeted toward more specific managed relocation scenarios. Expert opinion is, of course, only one part of multi-dimensional risk assessment that should involve diverse stakeholders and practical considerations.

Given the ability of environmental scientists to discern potential benefits and harms specific to a variety of ecological circumstances, these experts should be consulted in the development of principles, rules, and legal guidelines for managed relocation. Our results suggest that consultation should include scientists with both general environmental and taxonomic expertise. Systematic surveys of experts offer one tool for consultation, and conducted repeatedly over time, surveys can track up-to-date opinions of those most informed about biotic responses to climate change. Given the geographic scope and predicted magnitude of climate change under business-as-usual, it may be the greatest stress human activities have ever imposed on biodiversity, and this stress is outpacing research on its impacts. Experts feel that managed relocation can be part of the management strategy—in some instances—to reduce those impacts, and systematic measurements of expert opinion can be useful in developing those management plans.

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Contributions

- Contributed to conception and design: DJ, JH, JM, DS, MS
- Contributed to acquisition of data: DJ, JH
- Contributed to analysis and interpretation of data: DJ, JH, RCC
- Drafted and/or revised the article: DJ, JH
- Approved the submitted version for publication: DJ, JH, JM, DS, MS, RCC

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Competing interests

The authors do not have any competing interests regarding the work described in this paper.

Supplemental material

- **Appendix S1:** List of journals identified by the "Journal Citation Reports" of Thomson Reuters as being in the top quartile of publications in ecology, evolution, and conservation biology, based on their impact factors for 2008 is available online. doi: 10.12952/journal.elementa.000057.s001
- **Text S2:** Managed Relocation Survey 2010–11. doi: 10.12952/journal.elementa.000057.s002

Data accessibility statement

No additional data other than the survey results were generated.