Conservation Biology

Special Section: Balancing Conservation and Development to Preserve China's Biodiversity

Translocation of threatened plants as a conservation measure in China

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Abstract: *We assessed the current status of plant conservation translocation efforts in China, a topic poorly reported in recent scientific literature. We identified 222 conservation translocation cases involving 154 species, of these 87 were Chinese endemic species and 101 (78%) were listed as threatened on the Chinese Species Red List. We categorized the life form of each species and, when possible, determined for each case the translocation type, propagule source, propagule type, and survival and reproductive parameters. A surprisingly large proportion (26%) of the conservation translocations in China were conservation introductions, largely implemented in response to large-scale habitat destruction caused by the Three-Gorge Dam and another hydropower project. Documentation and management of the translocations varied greatly. Less than half the cases had plant survival records. Statistical analyses showed that survival percentages were significantly correlated with plant life form and the type of planting materials. Thirty percent of the cases had records on whether or not individuals flowered or fruited. Results of information theoretic model selection indicated that plant life form, translocation type, propagule type, propagule source, and time since planting significantly influenced the likelihood of flowering and fruiting on the project level. We suggest that the scientific-based application of species conservation translocations should be promoted as part of a commitment to species recovery management. In addition, we recommend that the common practice of within and out of range introductions in nature reserves to be regulated more carefully due to its potential ecological risks. We recommend the establishment of a national office and database to coordinate conservation translocations in China. Our review effort is timely considering the need for a comprehensive national guideline for the newly announced nation-wide conservation program on species with extremely small populations, which is expected to stimulate conservation translocations for many species in the near future.*

Keywords: assisted colonization, conservation introduction, endangered species, rare plants, reintroduction, species recovery

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Paper submitted August 27, 2014; revised manuscript accepted July 23, 2015.

Conservation Biology, Volume 29, No. 6, 1537–1551

DOI: 10.1111/cobi.12585

La Reubicación de Plantas Amenazadas como una Medida de Conservación en China

Resumen: *Evaluamos el estado actual de los esfuerzos de reubicación para la conservación de plantas en China, un tema poco documentado en la literatura científica reciente. Identificamos 222 casos de reubicación para la conservación que involucran a 154 especies, de las cuales 87 fueron especies endémicas de China y 101 (78%) están enlistadas como amenazadas en la Lista Roja de Especies Chinas. Clasificamos la forma de vida de cada especie y, cuando fue posible, determinamos para cada caso el tipo de reubicación, la fuente del propágulo, el tipo de propágulo, y los parámetros reproductivos y de supervivencia. Una proporción sorprendentemente grande (26%) de las reubicaciones de conservación en China fueron introducciones de conservación, implementadas en su mayoría en respuesta a la destrucción de hábitat a gran escala causada por la presa Tres Cañones y otro proyecto de energía hídrica. La documentación y el manejo de las reubicaciones variaron enormemente. Menos de la mitad de los casos tenían registros de la supervivencia de las plantas. Los análisis estadísticos mostraron que los porcentajes de supervivencia estuvieron correlacionados significativamente con la forma de vida de la planta y el tipo de materiales de plantación. El 30% de los casos tuvo registros de la floración y fructificación, o no, de los individuos. Los resultados de la selección de modelos de información teórica indicaron que la forma de vida de la planta, el tipo de reubicación, el tipo y fuente del propágulo, y el tiempo transcurrido desde la siembra influyen significativamente sobre la probabilidad de florecimiento y fructificación a nivel del proyecto. Sugerimos que la aplicación con bases científicas de la reubicación para la conservación de especies debería ser promovida como parte de un compromiso con el manejo de recuperación de especies. Además, recomendamos que la práctica común de las introducciones dentro y fuera de la extensión en las reservas naturales sea regulada de manera más cuidadosa debido a sus riesgos ecológicos potenciales. Recomendamos el establecimiento de una oficina y una base de datos nacionales para coordinar las reubicaciones para la conservación en China. Nuestro esfuerzo de revisión es oportuno si consideramos la necesidad de una guía nacional completa para el recién anunciado programa de conservación de especies con poblaciones extremadamente pequeñas a nivel nacional, el cual se espera que estimule la reubicación para la conservación de muchas especies en el futuro próximo.*

Palabras Clave: colonización asistida, especies en peligro, introducción de la conservación, plantas raras, recuperación de especies, reintroducción

Introduction

China is a globally recognized center of plant diversity, with about 10% (~30,000) of the world's higher plants and an estimated 10,000 endemic plant species (Yang et al. 2005). Habitat loss has resulted in the decline of many species. Over the past 50 years an estimated 200 plant species have become extinct in China (Chinese State Report on Biodiversity Editorial Committee 1998), whereas nearly 5000 Chinese plant species are considered threatened (Huang 2011; Ren et al. 2012*b*; Wild Fauna and Flora Protection and Nature Reserve Division et al. 2013). It is apparent that the threats to plant diversity in China are severe and are likely increase in the foreseeable future due to continued economic development and population growth. Global experience in plant conservation is increasingly adopting an integrated approach where ex situ methods are used to support the imperative of in situ conservation (Havens et al. 2006). Plant conservation translocations (a generic term encompassing the movement of plants for a conservation purpose), as one tool to support species recovery, has been practiced for many years (Maunder 1992), and the global portfolio of practical experience and technical literature (e.g., Guerrant & Kaye 2007; Menges 2008; Godefroid et al. 2011; Maschinski & Haskin 2012) and of supporting technical guidelines is increasing (Vallee et al. 2004; IUCN/SSC 2013).

Two reviews are global in scope (Godefroid et al. 2011; Dalrymple et al. 2012), and authors of both reviews used standard English databases to search for peer-reviewed articles, but they also relied heavily on accessible gray literature sources and surveyed different international practitioner groups. Only 3 Chinese reintroduction efforts were included in these recent reviews (Godefroid et al. 2011; Maschinski & Haskins 2012), most likely due to the language barrier.

In their global review, Godefroid et al. (2011) used Thomson's Web of Science database and a questionnaire targeting botanical gardens and other conservation organizations. The authors gathered information on 249 translocations of 172 plant species. They found that the average survival rate over all cases was 52% and that survival declined as time since translocation increased. On average <20% of the translocated species flowered or fruited. The authors called for better and longer post-planting monitoring.

Maschinski and Haskins (2012) examined aspects of conservation translocations in a book. Among the chapters, Dalrymple et al. (2012) provides the most comprehensive overview of reintroduction in terms of the number of species and projects. Using peer-reviewed and gray literature and interviews with the International Union for Conservation of Nature Species Survival Commission (IUCN/SSC) Reintroduction Specialist Group Members Database (IUCN 1998), the authors gathered data on projects involving approximately 700 plant taxa from Europe, the United States, Australia, and South Africa. Only 128 species of 700 provided useful data for quantitative meta-analyses of the roles of different factors in translocation success. They examined propagule history (ex situ derived vs. wild collected), species distribution range, number of propagule source populations, and whether the reintroduction location was within the species historical range or not. They found that endemic species were more likely to be successfully translocated than wide spread species, whereas other factors did not have significant impact. This result may be due to higher investments in conservation of endemic species. Two studies, Albrecht and Maschinski (2012) and Guerrant (2012), drew information primarily from the Center for Plant Conservation International Registry (http://www.centerforplantconservation.org/reintroduction/MN_ReintroductionEntrance.asp). This registry contains information on projects undertaken in the United States and Australia. They found that founding population size and propagule size positively correlates to translocation success for perennial plants.

All these reviews concluded that failure was common in conservation translocation projects and that poor documentation is hindering understanding of the reasons for failure. The concept of conservation translocation as a tool for species conservation has gained popularity among Chinese practitioners and the public in general, as evidenced by the frequent media reports in recent years. The Conservation Program for Wild Plants Species with Extremely Small Populations (hereafter referred to as Extremely Small Population Conservation Program), initiated by the China State Forestry Administration (State Forestry Administration of China 2012), signals acceptance of conservation translocations as an integral tool for species recovery in China (Ren et al. 2012*b*).

We reviewed the current status of conservation translocations of threatened plants in China and the particular challenges of these translocations. Specifically, we addressed the following questions: Which species are subject to conservation translocation, and among them how many are threatened species at the global or national scale? How successful are these translocations and what proportion of the projects have follow-up monitoring? What factors influence species conservation translocation success in China and how do these factors compare with those in other parts of the world? What needs to be changed to improve the effectiveness of conservation translocations as a tool for species conservation in China?

Materials and Methods

Definitions

Over recent years there has been significant evolution in reintroduction terminology, in part due to the interest in moving species out of recorded or historical ranges as a conservation response to climate change. *Conservation translocation* is the deliberate movement of organisms from one site for release in another with an intended conservation benefit (IUCN 2013). Conservation translocation is an effective conservation tool, but its use either on its own or in conjunction with other conservation solutions needs rigorous justification. Potential risks in a translocation are multiple. Translocation affects in many ways the focal species and their associated communities and ecosystem functions in both source and destination sites. Translocations of organisms outside their indigenous range are regarded as especially high risk given the examples of species released outside their indigenous ranges subsequently becoming invasive (IUCN 2013).

We used the terms as defined by the IUCN (2013) unless otherwise indicated. Specifically, we used *conservation translocation* for any conservation motivated movement of plants. We further classified conservation translocation into the following 4 categories: augmentation (synonymous with reinforcement), the adding of propagules to an existing population; reintroduction sensu stricto (s.s.) (synonymous with site reintroduction), translocation to a site recorded as having the species that is within the historical range area; within range introduction (Godefroid et al. 2011; Dalrymple et al. 2012), translocation to a site with no historical records of the species but within the historical range (referred to as range reintroduction by IUCN [2013] [We prefer the former term because it fits better with the meaning of *introduction*]); and conservation introduction, conservation motivated translocation beyond a recorded historical range. The latter situation may also be referred to as assisted colonization (also called managed relocation, assisted migration, assisted colonization), especially when global climate change is one of its motivations (Machinski & Haskins 2012).

Conservation translocation is synonymous with reintroduction sensu lato, which is a widely used general term that describes the controlled release of plant material into a natural area. Reintroduction also has a stricter definition, the release of plant propagules into an area where the plant formerly occurred but is now extirpated. This is sometimes referred to as reintroduction sensu stricto (Godefroid et al. 2011; Dalrymple et al. 2012), which is synonymous with site reintroduction as defined above. We followed the practice of Godefroid et al. (2011) and use the abbreviation s.s. when we mean reintroduction sensu stricto.

Collecting Information on Reintroduction Cases in China

To collect records of plant conservation translocations in China, we searched both English and Chinese databases. Because Godefroid et al. (2011) and Maschinski and Haskins (2012) did thorough searches in English databases (e.g., Web of Science and Google Scholar), we identified cases involving Chinese species that were cited in their reviews. We tried to identify additional cases published after 2011 by using a query modified from Godefroid et al. (2011) in Thomson's online Web of Science database and Google Scholar: (reintroduce* OR translocate* OR outplant* OR re-establish* OR transplant* OR Reinforce*) AND plant AND China. We then carried out similar searches in the Weipu Chinese journals database (in Chinese) using the following query: 珍稀植物 (meaning rare species) AND 保护 (meaning conservation) AND 回归 (meaning reintroduction) OR 恢复 (meaning restoration). We also used Baidu (a Chinese general search engine) to search for 濒危植物重引入 (meaning endangered plant reintroduction), 或 (meaning or), 濒危植物迁移 (meaning endangered plant transplant). We verified cases discussed in the gray literature (newspaper articles, government reports, etc.) by calling or emailing people or organizations identified in the reports. We asked the following questions: What species were translocated? Where was the translocation carried out? What kind of planting material (seeds, seedlings, saplings, reproductive plants, or others) was used? How many propagules were used? What was the source of the plant material (same population, nearby population, or mix of 2 or more populations)? When did you last monitor the restored population? What percentage of plants survived? Have plants flowered or fruited? Has recruitment been recorded? Who funded the restoration?

Finally, we contacted Chinese colleagues whom we knew had worked on threatened plant conservation and solicited their published articles, books, and conference abstracts. We verified species names, range, and endemism status with the Flora of China (FOC) (Wu & Raven 1994–2009). A few species were classified as narrow endemic. These species are not restricted to China, but their current ranges include only Guangxi, Guizhou, Yunnan, and northern Vietnam or fewer areas adjacent to one another that share similar tropical limestone and climatic characteristics.

Variables

We used 3 project-level parameters to measure translocation success: percentage of transplants still alive at the time of survey, whether any plants in a translocation population flowered, and whether any plants in a translocation population fruited. We were able to gather data on 6 factors likely to have some influence on the performance of the translocation populations: plant life form, propagule type, propagule source, number of propagules, time since planting to monitoring, and conservation translocation type. Life forms were of 3 types: herb, shrub, and tree. There was one palm and 2 cycads, which were categorized as shrubs. There were 4 translocation types: augmentation, reintroduction s.s., within range introduction, and conservation introduction. There were 3 propagule types: adult plants, saplings derived from normal seed germination, and saplings derived from vegetative propagation (i.e., tissue culture from adult plants, cuttings, or offshoots from large plants). Seeds were not listed because only one reintroduction trial used seeds, and they were mixed with adult plants as planting materials. The fates of these seeds were not subsequently monitored. Propagule source had 3 categories: same population, nearby population, or mixed populations. Finally, the number of propagules and time to monitoring were continuous variables. We did not analyze recruitment due to limited data (i.e., very small number of cases reported on recruitment).

Statistical Analyses

We took a 2-fold approach in our data analyses. First, we explored the relationship between the performance parameters and the 6 individual predictor variables (i.e., life form, propagule type, propagule source, number of propagules, time to monitoring, and conservation translocation type) separately. Single-factor ANOVA was used to analyze survival percentage (square root and arcsine transformed), whereas binary logistic regression was used for occurrence of plant flowering and fruiting. These statistical tests were carried out with SPSS 13.0 (SPSS 2005).

Second, to understand the relative fit of models containing various factors used to determine the success of the Chinese reintroduction trials, we used the information theoretic model selection approach (Burnham & Anderson 2002). To do this, we established a priori 3 sets of models, one for each of the 3 success parameters (Table 1). The predictor variables included plant life form, propagule type, propagule source, number of propagules, time to monitoring, and conservation translocation type. These variables are related to the characteristic of planting material (i.e., life form, propagule type, and propagule source), demographics (i.e., number of propagules), or nonplanting material related factors (i.e., time to monitoring and translocation type). There were 18 and 16 a priori sets of models for the survival and reproductive success analyses respectively, and they contained combinations of parameters from the 3 groupings (i.e., planting material characteristics, demographics, or nonplanting material related factors) (Table 1). The number of models for the survival parameter analyses (18) was more than that for reproductive parameter analyses (16) because the former had 2 additional models that incorporated the number of propagules, which we considered to matter more for survival than for reproductive parameters. We obtained the basic parameters (i.e., RSS or log likelihood) by running the specified models in SPSS 13.0 and then used Excel to calculate the Akaike information criterion (AIC) model selection related parameters (e.g., AIC, Δ_i, and Akaike weight) with formulas given by Burnham and Anderson (2002).

Table 1. Summary of information theoretic model selection statistics for multiple linear regressions in the examination of plant translocation in China.

Model[a]	*K*	*−2 log-likelihood*	*AIC or $QAIC_c$*[b]	Δ_i	*Akaike weights*
Survival as dependent variable (n = 107)					
1. full	8	60.45	−104.90	28.29	0.00
2. life_form, prop_type, prop_source, t_monitor, n_prop	7	62.31	−110.61	22.57	0.00
3. life_form, prop_type, prop_source, t_monitor, reintr_type	7	60.83	−107.67	25.52	0.00
4. prop_type, prop_source, t_monitor, n_prop	6	63.71	−115.41	17.77	0.00
5. prop_type, prop_source, t_monitor, reintr_type	6	62.00	−112.01	21.18	0.00
6. prop_type, t_monitor, reintr_type	5	62.97	−115.94	17.25	0.00
7. t_monitor, reintr_type, n_prop	5	69.07	−128.14	5.05	0.02
8. prop_type, reintr_type, n_prop	5	63.11	−116.22	16.97	0.00
9. prop_type, t_monitor, n_prop	5	63.88	−117.76	15.43	0.00
10. t_monitor, reintr_type,	4	69.44	−130.88	2.31	0.08
11. prop_type, t_monitor,	4	64.13	−120.26	12.93	0.00
12. t_monitor, n_prop	4	69.14	−130.27	2.91	0.06
13. reintr_type, n_prop	4	69.28	−130.55	2.64	0.07
14. prop_type, n_prop	4	64.02	−120.04	13.15	0.00
15. prop_type	3	64.39	−122.77	10.42	0.00
16. t_monitor*	3	69.59	−133.19	0.00	0.27
17. reintr_type*	3	69.54	−133.08	0.11	0.25
18. n_prop*	3	69.45	−132.91	0.28	0.23
Flowered or did not flower[c]					
1. full	9	11.36	22.42	8.39	0.00
2. life_form, prop_type, prop_source, t_monitor, n_prop	8	20.04	20.71	6.68	0.01
3. life_form, prop_type, prop_source, t_monitor, reintr_type	8	12.57	19.88	5.85	0.01
4. life_form, prop_type, prop_source, t_monitor	7	20.07	18.13	4.10	0.03
5. prop_type, prop_source, t_monitor, reintr_type	7	22.80	18.43	4.40	0.02
6. prop_type, prop_source, t_monitor, n_prop	7	26.33	18.82	4.79	0.02
7. life_form, prop_type, t_monitor	6	26.72	16.37	2.34	0.06
8. life_form, reintr_type, t_monitor	6	24.23	16.09	2.06	0.07
9. life_form, prop_type, prop_source	6	28.25	16.54	2.51	0.06
10. prop_type, t_monitor*	5	29.71	14.28	0.25	0.17
11. t_monitor, reintr_type*	5	45.14	16.00	1.97	0.07
12. prop_type, n_prop	5	49.71	16.51	2.48	0.06
13. prop_type, reintr_type*	5	45.54	16.04	2.01	0.07
14. n_prop	4	129.90	23.08	9.05	0.00
15. t_monitor*	4	48.47	14.03	0.00	0.19
16. prop_type*	4	51.86	14.41	0.38	0.16
Fruited or did not fruit[d]					
1. full	9	28.12	44.96	15.86	0.00
2. life_form, prop_type, prop_source, t_monitor, n_prop	8	40.54	42.73	13.62	0.00
3. life_form, prop_type, prop_source, t_monitor, reintr_type	8	28.89	40.40	11.30	0.00
4. life_form, prop_type, prop_source, t_monitor	7	41.02	38.20	9.10	0.01
5. prop_type, prop_source, t_monitor, reintr_type	7	48.14	39.63	10.53	0.00
6. prop_type, prop_source, t_monitor, n_prop	7	51.58	40.32	11.21	0.00
7. life_form, prop_type, t_monitor	6	45.54	34.58	5.48	0.04
8. life_form, reintr_type, t_monitor	6	51.07	35.69	6.59	0.02
9. life_form, prop_type, prop_source	6	52.48	35.97	6.87	0.02
10. prop_type, t_monitor	5	62.86	33.61	4.50	0.06
11. t_monitor, reintr_type,	5	63.68	33.77	4.67	0.06
12. prop_type, n_prop	5	75.20	36.07	6.97	0.02
13. prop_type, reintr_type	5	73.62	35.76	6.66	0.02
14. n_prop	4	98.38	36.35	7.25	0.02
15. t_monitor*	4	62.12	29.10	0.00	0.61
16. prop_type	4	79.25	32.53	3.43	0.11

[a] *Abbreviations: prop, propagule; t_monitor, time to monitoring; reintr_type, conservation translocation type; n_prop, number of propagules used for initial planting;* *, *best fit models among the a priori sets of models (values ≥2).*
[b] *Quasi-likelihood information criterion were used for logistic regressions on both flower and fruit analyses because both sets of data presented evidence of overdispersion, and it was also adjusted for small sample size, and thence $QAIC_c$ (Burnham & Anderson 2002). Note that K was adjusted accordingly when $QAIC_c$ was used.*
[c] *A binary variable as dependent variable (n = 67). Variance inflation factor c = 9 used to calculate QAICc.*
[d] *A binary variable as dependent variable (n = 64). Variance inflation factor c = 5 used to calculate $QAIC_c$.*

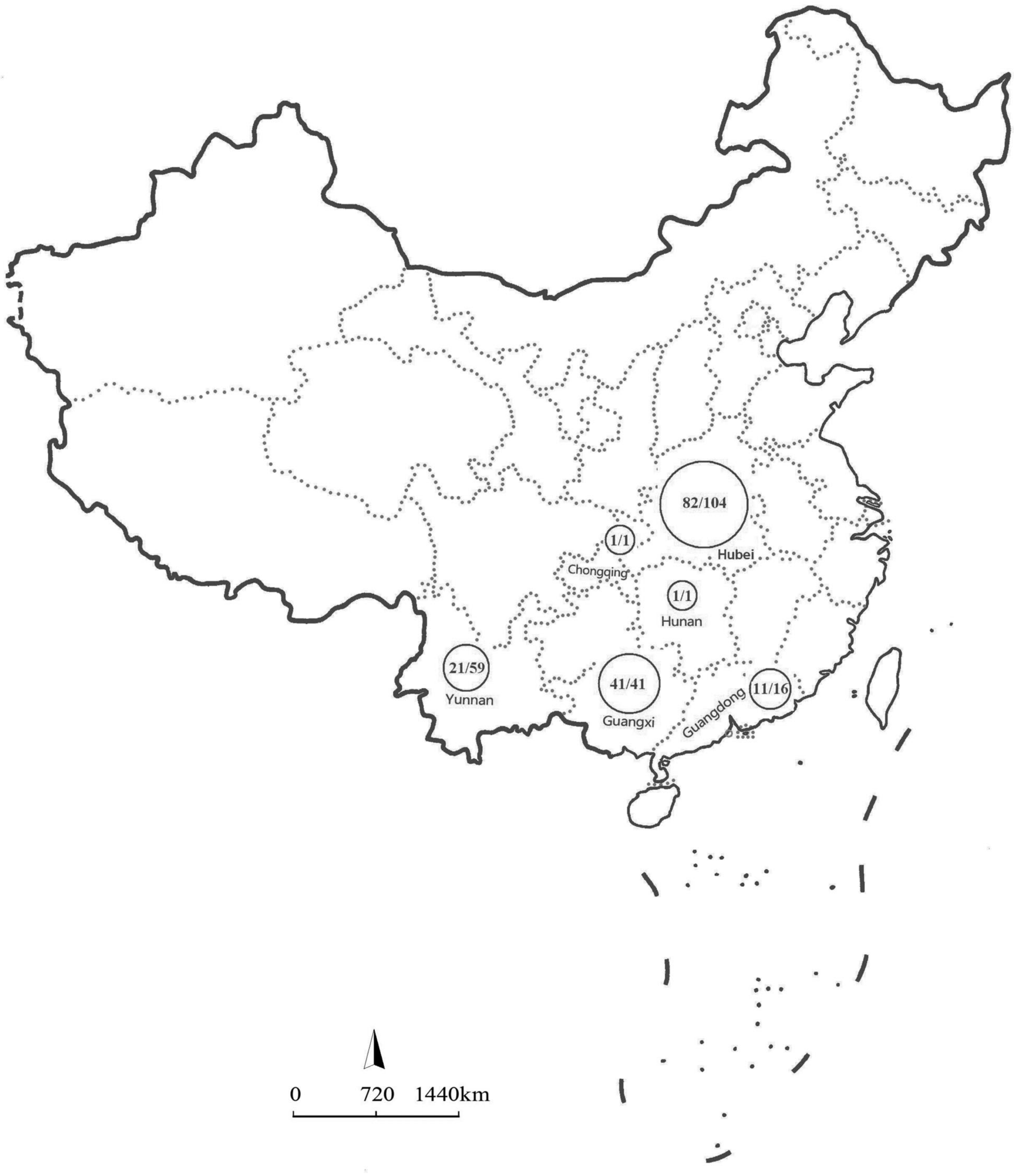

Figure 1. Locations of and number of species/projects involved in plant conservation translocation (respectively) in China since 1980. Provinces were not named if no conservation translocation activities were known.

Results

We identified 222 plant conservation translocation projects in China, all of which occurred in central and southern provinces (Fig. 1). Hubei (n = 104), Yunnan (n = 59), and Guangxi (n = 41) provinces had the most projects. These are among China's most botanically diverse provinces. These translocations involved 154 species, 87 of which are Chinese endemic species (Figs. 2a & 2b). In Fig. 1, the number of species adds up to more than the total number of species (154) known to have been subject to conservation translocation

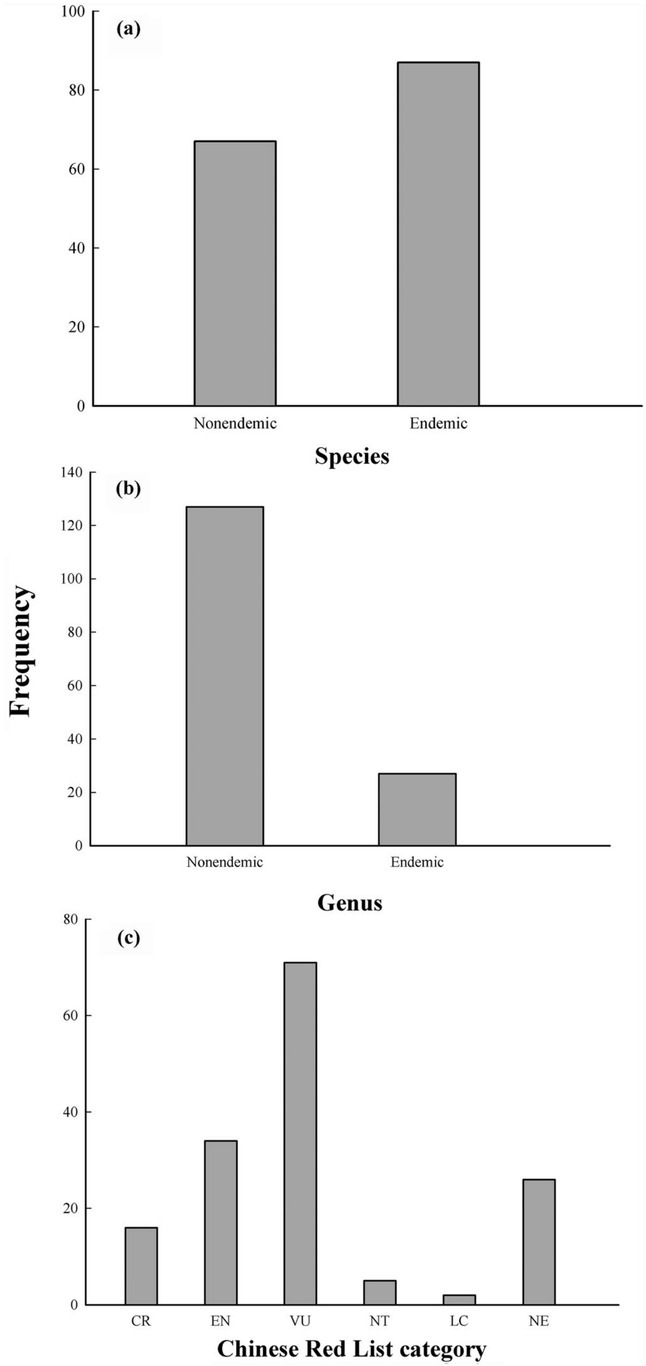

Figure 2. Number of (a) endemic and nonendemic species and (b) endemic and nonendemic genera and (c) species by threat category (Chinese Red List) subject to conservation translocations in China (CR, critically endangered; EN, endangered; VU, vulnerable; NT, not threatened; LC, least concern; NE, not evaluated by Chinese Red List).

in China because 3 species were translocated in 2 provinces. There were 136 species of angiosperms, 17 gymnosperms and one Pteridophyta, representing a total of 53 families and 116 genera. Two of the families (Eucommiaceae and Ginkgoaceae) and 22 genera are endemic to China. The Orchidaceae had the largest number of translocated species (35 spp.), followed by Magnoliaceae (17 spp.), Pinaceae (6 spp.), Aceraceae (5 spp.), Fabaceae (5 spp.), Oleaceae (5 spp.), and Theaceae (5 spp.). Forty-five species (29%) were herbaceous plants, 22 (14%) were shrubs (including 1 palm and 2 cycads), and the rest (56%) were trees (Fig. 3a & Supporting Information).

Eighty-four percent of the species were listed on the Chinese Red List (Wang & Xie 2004), which is based on IUCN Red List criteria. One hundred and one species (78%) were critically endangered, endangered, or vulnerable (Fig. 2c).

Of the 222 projects, 60 (27%) were augmentations, 16 (7%) reintroductions s.s., 89 (40%) within range introductions, and 57 (26%) conservation introductions (Fig. 3b & Supporting Information). The majority of projects (74%) used saplings or young plants derived from seeds as transplanting materials, 20% of them used adult plants (one mixed with seeds), and 5% used saplings derived from vegetative propagations (Fig. 3c). Nearly half of the cases (41%) used material from a nearby population as their source material for planting (Fig. 3e), and 23% of the projects used material from remnant populations in the translocation sites. Twelve projects used material from mixed sources. Many projects (31%) had no records on the source of the material used. Thirteen percent of projects were carried out with some kind of experimental set up (Fig. 3f), for example, testing the effects of sun versus shade on plant survival. Sixty-four percent of projects recorded number of propagules used, and number of propagules ranged from 1 to 5000 (mean = 196.5).

Overall, 149 (67%) projects were related to threatened species translocation programs tied to the construction of Three-Gorge Dam (108 cases) and the Hongshui River Hydrological Power Plants (41 projects). The earliest conservation translocations occurred around the mid-1980s (Fig. 3d, ~70 projects) and were carried out by the Wuhan Botanical Garden in response to the approval (not implementation) of the Three-Gorge Dam project (Ye & Chen 2004). Most of these 70 projects were within range introductions and some were conservation introductions (Supporting Information; Ye et al. 2002; Ye & Chen 2004). These translocations were undertaken within natural forests in the Jiugongshan National Nature Reserve and were not subject to artificial management, such as supplemental watering and weeding, after the initial planting event. Similarly, the recipient sites of the translocations for a large number of threatened plants (mostly orchid species) were also natural forests (e.g., in the Yachang Orchid Nature Reserve) (Liu et al. 2012).

One hundred and seven cases (48%) had monitoring programs that gathered survival data. The

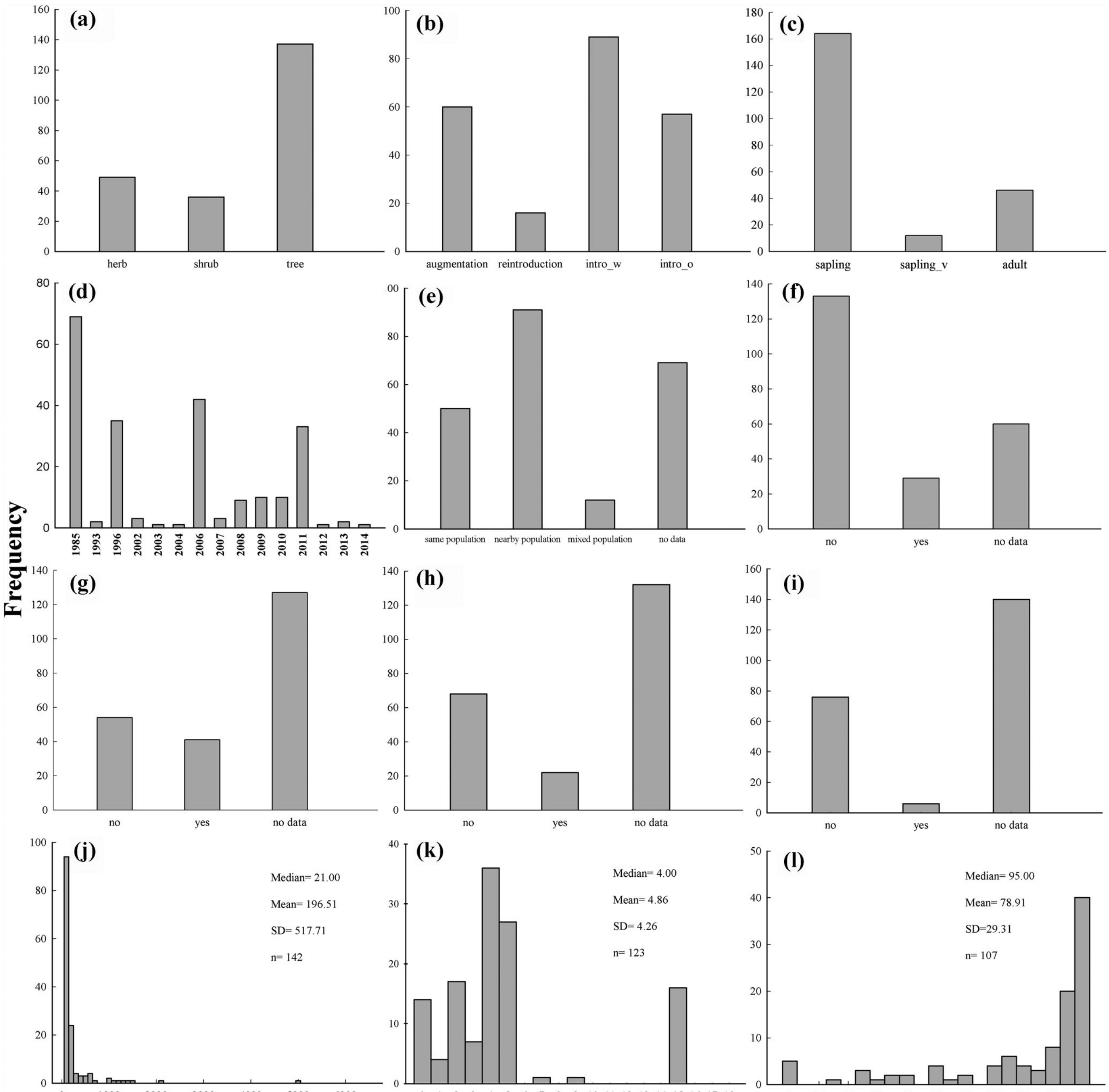

Figure 3. Number of conservation translocation projects in China relative to (a) plant life form, (b) translocation type (w, within range introduction; o, out of range introduction), (c) propagule type (v, saplings from vegetative propagation), (d) translocation year, (e) propagule source, (f) use of experimental design, (g) flowering of translocated populations, (h) fruiting of translocated populations, (i) recruitment of translocated population, (j) number of propagules used, (k) time (years) to monitoring since planting, and (l) percent survival of propagules.

period of monitoring after planting ranged from 0.3 to 15 years (mean = 4.9 years) (Fig. 3k). Range of percent survival was 0–100% (mean = 78.9%) (Fig. 3l). The individual factor analyses indicated that life form (MS = 1.437, $F_{2,\,104} = 9.667$, $P < 0.001$) and propagule type (MS = 1.270, $F_{2,104} = 8.361$, $P < 0.001$), but not other factors, were significant predictors of survival (Fig. 4a). Specifically, herbs had a higher survival percentage than shrubs and trees (Fig. 4a), and saplings derived from seeds had a higher survival percentage than saplings derived from vegetative means and adult plants (Fig. 4b).

The information theoretic model selection analyses indicated that factors not related to planting material characteristics (i.e., time to monitoring or translocation

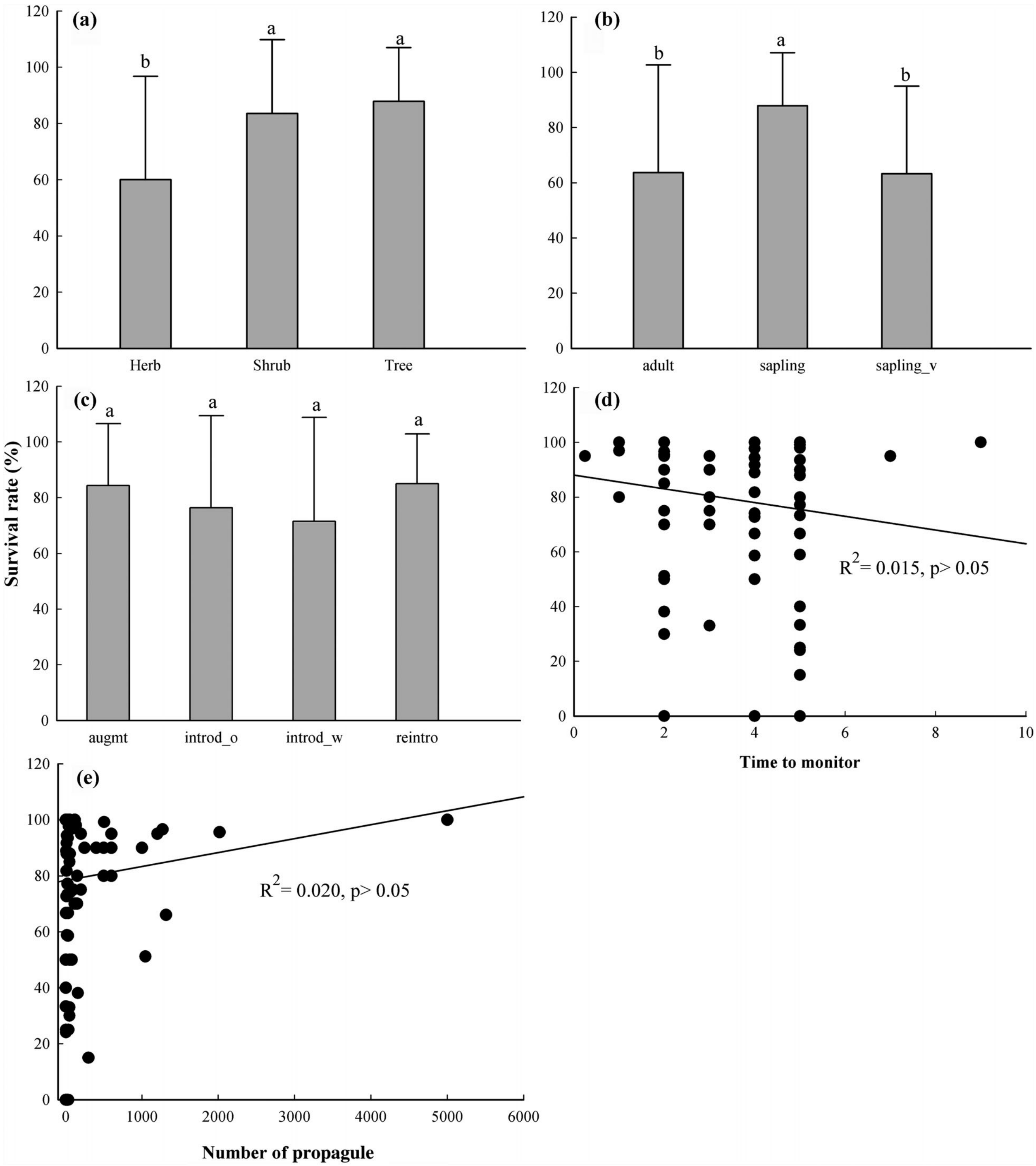

Figure 4. Mean (SD) of percent survival of conservation translocations relative to (a) life form, (b) propagule type (v, saplings from vegetative propagation), and (c) translocation type (w, within range introduction; o, out of range introduction) and percent survival versus (d) time (years) to monitoring since planting and (e) number of propagules. Bars with different letters were significantly different from each other based on single factor general linear regression analyses.

type) and demographic factor (i.e., the number of propagules used) were the best predictors of percent survival (Table 1 & Fig. 4c). Specifically, survival declined as the time to monitoring increased (Fig. 4d), but survival increased as the number of propagules increased (Fig. 4e). However, none of these individual regression models was statistically significant, indicating that these relationships were weak. The statistically significant pair-wise correlations between life form and time to monitoring (Pearson correlation = −.0.417, $P < 0.001$), between propagule type and time to monitoring (Pearson correlation = 0.468, $P < 0.001$), and between propagule type and reintroduction type (Pearson correlation = 0.262, $P = 0.006$) were likely the reason models with significant factors (i.e., time to monitoring and propagule type) were not the best among the a priori models.

Sixty-seven cases (30% of the total projects) monitored flowering of translocated plants (Fig. 3g). Among these, 36 translocation populations flowered (Fig. 3g). The individual factor analyses indicated that life form (Wald = 27.007, df = 2, $P < 0.001$), introduction type (Wald = 22.494, df = 3, $P < 0.001$), propagule type (Wald = 16.630, df = 2, $P < 0.001$), propagule source (Wald = 31.614, df = 2, $P < 0.001$), and time to monitoring (Wald = 21.973, df = 1, $P < 0.001$) but not the number of propagules were significant predictors of whether a translocation population flowered (Fig. 5). Specifically, a higher proportion of translocated herbs (97%, 34 of 35 cases) flowered than translocated shrubs (24%, 4 of 17 cases) and trees (7%, 3 of 43 cases) (Fig. 5a), Furthermore, introductions within (86%, 6 of 7 cases) and outside the range of the species (85.7%, 18 of 21 cases) had higher proportions of populations flower than augmentation (23.5%, 12 of 51 cases) or reintroduction s.s. (31.3%; 5 of 16 cases; Fig. 5b). In all 21 cases that used adult plants as translocation material, the populations flowered (100%). In 9 of the 11 cases (81.8%) that used saplings derived from vegetative propagations, populations flowered (Fig. 5c). Flowering was significantly higher for populations established with saplings derived from vegetative propagation than for populations established with saplings derived from seeds (17%, 6 of the 39 cases). Furthermore, a higher proportion of populations established with planting materials from a nearby population (77.1%, 27 of 35 cases) or from a mixed population (72.7%, 8 of 11 cases) flowered than populations established with materials from extant populations (12.2%, 6 of 49 cases; Fig. 5d). Finally, the more time that elapsed between planting and monitoring, the more likely a translocation population was to flower. The mean time to monitoring since planting for translocations that flowered was 4. 5 years (SD 1.36) and was 1.5 years (SD 1.57) for populations that did not flower.

Information theoretic model selection on flowering of a translocation population indicated that the best models included time to monitoring and propagule type, alone or together, and time to monitoring together with translocation type (Table 1 & Fig. 5). With the exception of the number of propagules, all the pairwise correlations between the predictor variables were significant. The lack of independence among the predictor variables was, as with the survival analyses, likely the reason some models that included significant predictors, as indicated by the single factor analyses, were not among the best set of models.

Sixty-four translocation populations (29%) were tracked for fruiting (Fig. 3h). Among these, 22 populations fruited (Fig. 3h). The single factors analyses yielded similar results to the flowering analyses reported above. Information theoretic model selection relative to fruiting indicated that the best model included time to monitoring alone (Table 1). Specifically, the more time that elapsed between planting and monitoring, the more likely it was that at least one plant within the population fruited.

Only 7 projects involving 5 species resulted in recruitment (Fig. 3i). One of these was the site reintroduction of wild rice (*Oryza rufipogon*) (Liu et al. 2004). The project was initiated in 1993, monitoring was performed for 5 years, and both seeds and adult plants were used as propagules. The other project with recruitment was with a lady's slipper orchid (*Paphiopedilum malipoense*). The project was a reintroduction s.s. and was initiated in 2004 and monitored yearly for 10 years (Z. J. Liu, personal communication). Five thousand large plants, each derived from a healthy offshoot from an adult plant cultivated in a shade house, were used as propagules. Survival was nearly 100% (Supporting Information).

Four other translocation projects, 2 projects each for *Primulina tabacum* (Primulaceae) and *Tigridiopalma magnifica* (Melastomataceae), resulted in recruitment. They were carried out by the South China Botanical Garden (Supporting Information; Ren et al. 2010, 2012*a*). Detailed research on both species' biology and ecology was carried out before the conservation translocation was undertaken. Two of the projects were augmentations, one for each species, one project was site reintroduction (for *P. tabacum*), and the other was out of range introduction (*T. magnifica*).

Many of the conservation translocations undertaken in response to the Three-Gorge Reservoir project flowered or fruited, but these events were not documented in detail (e.g., which species or how many individuals) (Ye et al. 2002). One exception to this was *Dipteronia sinensis* (Sapindaceae). A within range introduction of the species was conducted in Jiugongshan Nature Reserve, and the population was recorded to have produced abundant and well-dispersed seeds that resulted in recruitment (Ye et al. 2002).

Discussion

The number of conservation translocations undertaken in China, as shown in our study, is surprisingly large, considering that only 3 cases were cited in the 2 recent reviews (Godefroid et al. 2011; Dalrymple et al. 2012). Many of these projects were published in Chinese language journals, books, or conference proceedings or were simply unpublished. Some projects were

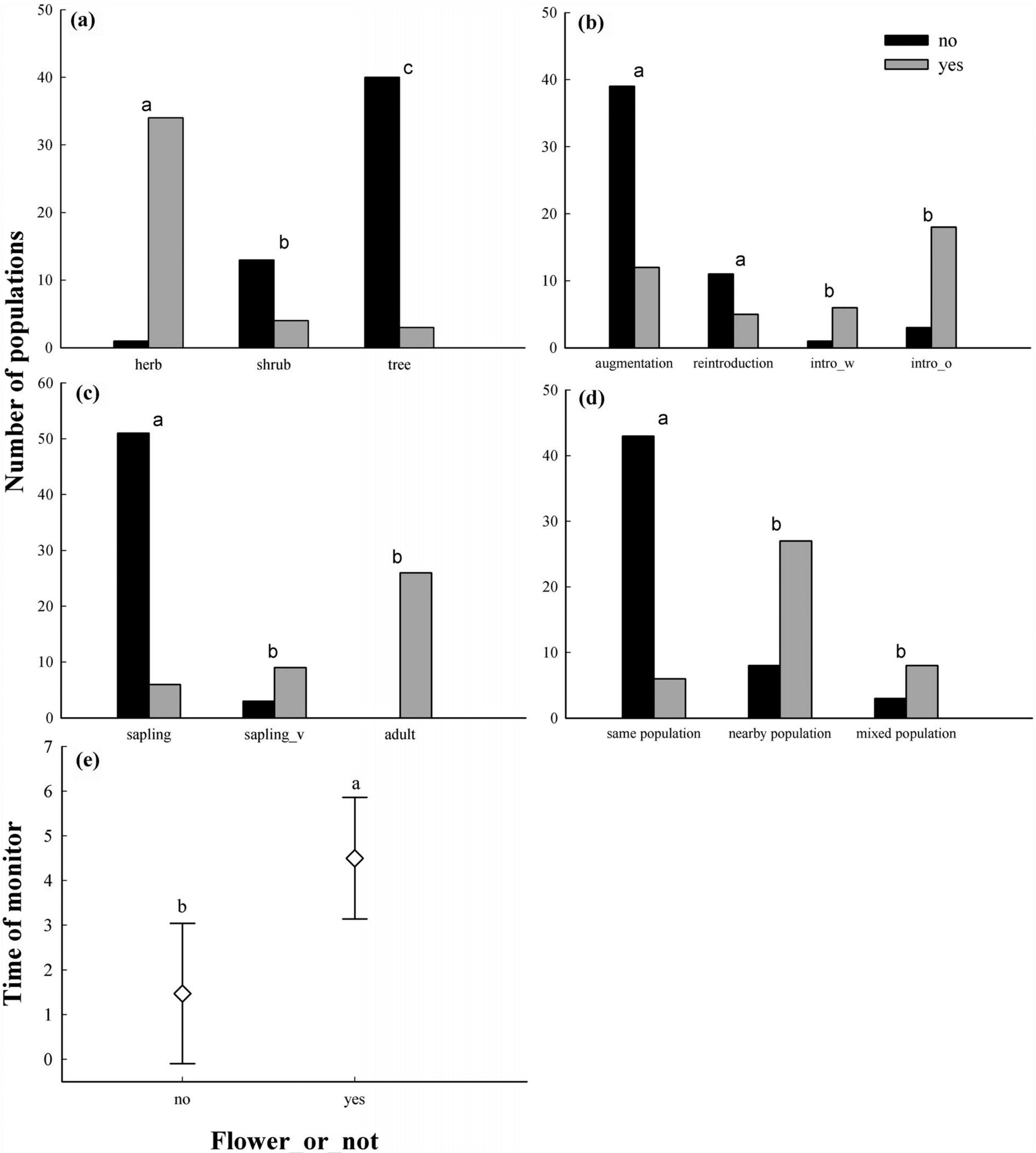

Figure 5. Number of translocation populations that flowered (yes or no) relative to (a) life form, (b) translocation type (w, within range introduction; o, out of range introduction), (c) propagule type (v, saplings from vegetative propagation), and (d) propagule source. (e) Average time (years) to monitoring since planting of translocations that flowered and translocations that did not flower. Groups of bars within a panel with different letters had significantly different proportions of translocations that flowered based on binary logistic regressions.

extensively reported by national or local newspapers, such as the *Cycad debaoensis* reintroduction in Debao county of Guangxi Zhuang Autonomous Region in 2008 (http://www.gx.xinhuanet.com/newscenter/2014-06/03/c_1110959393.htm).

Motivation Behind Chinese Plant Conservation Translocations

The initiation of the Three-Gorge Dam project in the 1980s caused conservationists to consider moving populations of rare and threatened species to new locations that were considered secure (Ye et al. 2002; Chen et al. 2005), and this motivation was responsible for 2 of the 4 spikes in the number of conservation translocation projects (Fig. 3c). Botanical gardens, especially Wuhan Botanical Garden, under the umbrella of the Chinese Academy of Science, were charged with researching and implementing the translocation of threatened plants. Another hydropower project, the Hongshui River hydropower plant project, also stimulated the large-scale translocation of rare and threatened plant species (the third spike in the number of projects [Fig. 3c]). The hydropower plants are located in species-rich subtropical southwestern China and are adjacent to the then newly established Guangxi Yachang Orchid Nature Reserve (Liu et al. 2012).

Since 2008, as Chinese botanical gardens and conservation researchers and practitioners became more familiar with the work of Western plant conservation biologists, an increased number of translocations have been carried out. This was in part motivated by the Conservation of Species with Extremely Small Populations project (China State Forestry Administration) and other species conservation programs co-sponsored by the State Forestry Administration and provincial Bureau of Forestry. Financial support for rare and threatened tree species from Botanic Gardens Conservation International (BGCI) has also played a role. Fifty-three of the 222 projects (24%) were initiated because of BGCI's one-time funding (fourth spike in the number of projects [Fig. 3c]; Supporting Information).

Number of Introduction Trials

In our review, we found that a large number of the translocation projects (67% of all cases) were developed in response to habitat loss caused by the Three-Gorge Dam and other large hydropower projects. Rescue projects initiated in response to habitat loss from development or infrastructure projects, that include the translocation of threatened species, are not uncommon. However, large scale plant translocations are uncommon because such actions are expensive and labor intensive (Liu et al. 2012). The only other known large-scale plant rescue occurred in Brazil (Jasper et al. 2006), where 141,686 specimens in 3 plant families were translocated (Orchidaceae, Bromeliaceae, and Cactaceae).

In fact, with 2 exceptions, all conservation introduction cases we included here were conducted due to hydropower construction. One such conservation introduction prevented the extinction of an endemic shrub (*Myricaria laxiflora*), which is restricted to the Three-Gorge Dam area (Chen et al. 2005), and was the only known case where a plant species' entire natural distribution range was below a reservoir's submerge line. Funding was available from the Chinese Academic of Sciences for research on the basic biology and ecology of the species (e.g., habitat requirements) before the translocations. Three sites at different branches of the Yangzi River were chosen as recipient sites, each with a different population source to preserve the genetic architecture of the original populations. Survival 2 years after transplantation ranged from 51% to 97%.

In contrast, the Hongshui River plant translocations were carried out with little or no prior research because funds supporting the plant translocations were made available only months before the first scheduled inundation (Liu et al. 2012). The recipient site for the 31 orchid species was in natural forest at an elevation 600 m higher than the source sites, accordingly, many of the orchids were translocated out of their natural altitudinal range (Liu et al. 2012).

Factors Affecting the Performance of Chinese Plant Conservation Translocations

Consistent with patterns documented in recent reviews (e.g., Dalrymple et al. 2012), less than half the reintroduction projects in China monitor or document the nature and outcome of the translocations. Survival is often the only parameter recorded. Very few projects monitored flowering or fruiting in the translocated populations. Among the 6 examined factors (translocation type, propagule type, number of propagules, propagule source, time to monitoring, and plant life form), only life form and propagule type were significant predictors of survival of translocated populations, but the 2 variables were not independent of each other. In general, propagule type and size are important factors in the success of a conservation translocation, and the use of large plants (e.g., saplings vs. seedlings) has resulted in greater survival (Godefroid et al. 2011; Albrecht & Machinski 2012; but see Dalymple et al. 2012). In our study, translocations using saplings derived from seeds had higher survival rates than those using adults (older material) or saplings derived from vegetative means. Perhaps the advantage of using large material does not extend to adult size, when translocation vulnerability becomes large again. The majority (73.5%) of the translocations involved herbaceous species and used adults as planting material; therefore, it is not surprising that herbaceous plants had a lower survival percentage than trees and shrubs.

Survival percentage increased as the size of the founder population increased, but this relationship was not significant statistically in our study. This pattern is nonetheless consistent with expectations based on the small population paradigm (sensu Caughley 1994) and was reported in other reviews (Godefroid et al. 2011; Albrecht & Maschinski 2012; but see Dalrymple et al. 2012). Translocated populations are often small, and choices of propagule type are restricted (Guerrant 1996; Albrecht & Maschinski 2012). Translocations of a small number of founder individuals can be vulnerable to the effects of demographic and environmental stochasticity that can work separately or interactively to increase the risk of population extinction. Small populations may also be prone to Allee effects, in which low population density or size can reduce fitness and per capita growth rate and can lead to eventual extinction of small population (Groom 1998; Hackney & McGraw 2001).

Mixed propagule sources, with the opportunity for increased genetic diversity, should promote translocation and reintroduction success (Godefroid et al. 2011; Albrecht & Machinski 2012). In our study, translocated populations derived from propagules from different populations did not result in higher survival percentages.

Plant life form was a significant predictor of whether a translocation population flowered and fruited. Translocations of herbaceous species showed a greater success in flowering and fruiting compared with trees and shrubs. This may be due to the fact that it takes much longer for trees and shrubs to reach reproductive maturity than herbs. In addition, translocation type was a significant predictor of whether the translocation population would flower and fruit. A greater number of conservation introductions progressed to flowering and fruiting than other types of translocations. This is somewhat unexpected because one of the challenges facing out of range introduction is stress from possible climatic mismatch (Liu et al. 2012). Nevertheless, what we observed here may be due to data bias (i.e., most of the translocation cases with flower and fruit data were of herbaceous plants and many of these were orchids translocated to an out of range site due to dam construction). Future studies should compare the relative long-term performance of translocations of different types.

Propagules derived from tissue culture were used in a few translocation projects. This technique was used to generate saplings to be used as sole (for *Primulina tabacum*) or supplemental planting materials (for *Tigridiopalma manifica*) (Ren et al. 2010, 2012*a*). All these populations have progressed to flowering, fruiting, and recruiting. The surplus plants obtained from issue culture were used for commercial horticulture, as a way to minimize poaching pressure. Using in vitro propagation for reintroduction is widely used in the United States, United Kingdom, and Australia, especially for orchids, cacti, and ferns (Haskins & Pence 2012).

Future Directions

Conservation translocations have been adopted as a tool for species conservation in China. One of the commitments by the Chinese government to the Global Strategy for Plant Conservation is to provide ex situ protection for 60% of the threatened plant species, of which 10% would be included in conservation translocation programs by 2020 (China's Strategy for Plant Conservation Editorial Committee 2008). To fulfill this commitment, at least 300 species need to be subject to reintroduction, assuming the estimation that China has approximately 5000 threatened plant species (Chinese State Report on Biodiversity Editorial Committee 1998) is correct.

We found that 154 species have been subject to some form of conservation translocation. The great majority (121) of these species were listed as threatened (Wang & Xie 2004). This indicates that China has already made some progress toward this goal. It is reasonable to expect that more conservation translocations delivered as a component of an integrated recovery plan will be carried out soon, as a new program to encourage reintroduction (e.g., the Extremely Small Population Conservation Program to be implemented over the next few years following the launch by the State Forestry Administration, P.R. China in 2012). Moving forward, integration of recent guidelines on plant reintroduction (Machinski & Haskin 2012; IUCN 2013) into policy and procedures for Chinese practitioners, will no doubt improve the success of translocation activities. Similarly, there is a need to translate these new guidelines into Chinese.

Our review revealed a practice in China to establish ex situ living collections in natural forests (often within nature reserves), both within and out of a species' known range. This practice bears some similarity to that of quasi in situ plant conservation approach (Volis & Blecher 2010). By the Chinese nature reserve laws, it is illegal to introduce species not naturally present at the site to the core areas of a nature reserve, but it is permitted in experimental zones (Regulations on the Nature Reserve of China, http://www.gov.cn/ziliao/flfg/2005-09/27/content_70636.htm). Nevertheless, some of these experimental zones consisted of intact and diverse forests, some with populations of threatened and rare species, an example being the Three-Gorge Dam translocation site at Jiugongshan National Nature Reserves (Ye et al. 2000, 2002; Ye & Chen 2004) and the Hongshui River translocation (Liu et al. 2012). Introducing species not native to the site may cause conservation problems such as pest and pathogen transmission, hybridization, and introduction of an invasive species (Davidson & Simkanin 2008; Ricciardi & Simberloff 2009). Ye et al. (2002) observed strong seed dispersal ability and abundant seedling recruitments by *Dipteronia sinensis*, one of the endangered species of the Three-Gorge Reservoir area that was a within range introduction to the Jiugongshan Nature Reserve, and warned of the potential negative impacts of the introduction on local plant communities. We recommend that this practice, which is still common to this date, be stopped or at least regulated more carefully.

Conservation introduction is recognized as a high-risk activity (IUCN 2013), and the IUCN (2013) promotes a precautionary approach to its use and significant investment in research and risk assessment. (Ren et al. 2012*a*, 2014) recently carried out conservation introductions for

Camellia changii (Theaceae) and *Tigridiopalma magnifica* (Supporting Information) in response to the suspected loss of the species pollinator from the remnant population site as a result of climate change. The outcome of these out of range conservation translocations is not yet known.

Systematic research on target species' biology and ecology is an essential component of a conservation translocation (IUCN 2013), and projects structured as experiments have a much greater likelihood of generating reliable information to guide future projects and improve success rates (Guerrant 2012). The performance of the majority of the projects we reviewed cannot be fully assessed due to lack of project documentation and inadequate or absent monitoring. Certain Chinese government agencies, such as the State Forestry Administration, provincial forestry bureau, and the international NGO BGCI tend to fund episodic, short-term actions related to conservation translocations and ex situ conservation, but they typically do not fund the basic research needed to ensure success. In contrast, agencies such as the National Science Foundation of China do fund basic research on rare and threatened species, but on topics that are tied to certain basic research questions. This divide of institutional culture, one focused on practical delivery, one focused on academic research and peer reviewed publication, has retarded the development of plant conservation biology in China. Conservation biology and its practical application need to combine the resources, physical and intellectual, of both parties to increase the effectiveness of plant conservation. To encourage and strengthen future reintroduction monitoring program, we suggest that government funding agencies increase co-sponsorship to conservation translocation projects. We recommend establishing a national office and database for the coordination of and support for threatened plant recovery projects, including conservation translocations when they are required, based on the model of the Center for Plant Conservation in the United States.

Establishing protected areas remains the most effective strategy for conserving plant diversity. However, conservation translocation as part of a science based recovery plan may be necessary in situations to prevent species extinction. As China continues with new and massive infrastructure projects, we expect to see further translocations undertaken in response to habitat loss. China has broad experience in implementing the translocation of threatened plant species. Nevertheless, there is an urgent need to adopt a more systematic approach that unifies the approaches of the different stakeholders, builds on resident expertise and experience, and uses the existing guidelines as foundations for national protocols.

Acknowledgments

We thank Y. Wang for help in making maps. Grants from the National Science Foundation of China (grant no. 31360146 to H.L. and 31470450 to J.Y.G.) and from the Guangxi Science and Technology Bureau (grant no. 12217-04) to H.L. made this analysis possible.

Supporting Information

A table of plant reintroduction locations, types, and monitoring information in China (Appendix S1) and a list of and information on species subject to conservation translocation in China over the past 30 years (Appendix S2) are available online. 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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