Conservation genetics in the recovery of endangered animal species: a review of US endangered species recovery plans (1977–1998)

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Abstract

Conservation genetics in the recovery of endangered animal species: a review of US endangered species recovery plans (1977–1998).— The utility of genetic data in conservation efforts, particularly in comparison to demographic information, is the subject of ongoing debate. Using a database of information surveyed from 181 US endangered and threatened species recovery plans, we addressed the following questions concerning the use of genetic information in animal recovery plans: I. What is the relative prominence of genetic vs. demographic data in recovery plan development? and, II. When are genetic factors viewed as a threat, and how do plans respond to genetic threats? In general, genetics appear to play a minor and relatively ill–defined part in the recovery planning process; demographic data are both more abundant and more requested in recovery plans, and tasks are more frequently assigned to the collection / monitoring of demographic rather than genetic information. Nonetheless, genetic threats to species persistence and recovery are identified in a substantial minority (22 %) of recovery plans, although there is little uniform response to these perceived threats in the form of specific proposed recovery or management tasks. Results indicate that better guidelines are needed to identify how and when genetic information is most useful for species recovery; we highlight specific contexts in which genetics may provide unique management information, beyond that provided by other kinds of data.

Key words: Conservation genetics, Endangered species, Endangered species recovery plans.

Resumen

Genética de la conservación para la recuperación de especies animales en peligro de extinción: revisión de los planes de recuperación de especies en peligro de extinción de Estados Unidos (1977–1998).— La utilidad de los datos genéticos en los esfuerzos conservacionistas, en particular en comparación con la información demográfica, es objeto de un continuo debate. Utilizando una base de datos con información sobre los 181 planes de recuperación de especies amenazadas y en peligro de extinción de Estados Unidos, hemos estudiado las siguientes cuestiones referentes al uso de la información genética en los planes de recuperación de especies animales: I ¿Cuál es la importancia relativa de los datos genéticos en comparación con los demográficos en el desarrollo de los planes de recuperación? y II ¿Cuándo se considera que los factores genéticos constituyen una amenaza, y cómo responden los planes a esas amenazas genéticas? En general, parece que la genética sólo desempeña un papel menor y relativamente mal definido en el proceso de planificación de la recuperación de especies; los datos demográficos son más abundantes y más solicitados para la elaboración de planes de recuperación, y las acciones que se llevan a cabo con frecuencia se enfocan más a las recopilación/observación de los datos demográficos que a la obtención de información genética. No obstante, las amenazas genéticas para la supervivencia y recuperación de especies se indican como un importante factor minoritario (22 %) en los planes de recuperación, si bien la respuesta a esas amenazas mediante medidas de gestión o recuperación específicas es poco uniforme. Los resultados apuntan a que se necesitan unas directrices más claras para determinar cómo y cuándo resulta más útil la información genética para la recuperación de especies; hemos resaltado contextos concretos en los que la genética puede proporcionar una valiosísima fuente de información para la gestión de esas cuestiones, superior a la que se pueda obtener a partir de otros datos.

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Introduction

Interest in the application of genetics to conservation biology has grown enormously in the last 20 years. With it has come vigorous debate both for and against the utility of genetic studies in practical conservation contexts. On one hand, it is acknowledged that genetic characteristics have the potential to influence a group's ability to persist over both the short and long term (SCHONEWALD–COX et al., 1983; ELLSTRAND & ELAM, 1993; KELLER et al., 1994, FRANKHAM, 1995; PEAKALL & SYDES, 1996; HOGBIN & PEAKALL, 1999; SACCHERI et al., 1998; HEDRICK & KALINOWSKI, 2000). On the other hand, few direct links between extinction and genetics have been firmly established, leading some to argue that other more immediate concerns, such as demographic characteristics and population dynamics, should almost always have primacy over genetic considerations (LANDE, 1988; CARO & LAURENSON, 1994; CAUGHLEY, 1994; SCHEMSKE et al., 1994). Resolving prioritization of recovery efforts is crucial in a continuing climate of limited funding for both conservation research and endangered species recovery efforts.

In the USA, the primary legal mechanism for protecting and subsequently managing endangered species is the Endangered Species Act of 1973 (ESA). One fundamental goal of the ESA is recovery of listed species, *i.e.* biological rehabilitation to a point where the threat of extinction no longer exists. To this end, the ESA provides for the development of a recovery plan for each listed species; each plan must identify explicit criteria for evaluating recovery, a set of specific management actions to achieve this recovery, and an outline of estimated time and costs of implementing these actions. Within this recovery process, genetics can play an important role by providing information relevant to the development of management and breeding strategies to promote species persistence, including conservation of genetic diversity and reduction of threats such as inbreeding and outbreeding depression (HEDRICK & KALINOWSKI, 2000). In fact, a number of individual cases (in both Europe and the US) have clearly demonstrated the utility of genetic analysis and/or intervention in the management of endangered animal groups, especially in the alleviation of inbreeding depression via migration or translocation (*e.g.* WESTEMEIER et al., 1998; MADSEN et al., 1999; VILA et al., 2003). Nonetheless, continuing disagreement over the general importance of genetic factors in species persistence, in combination with the relative difficulty of obtaining relevant genetic data, may negatively impact the use of genetic approaches in endangered species recovery planning. Indeed, the prevalence, importance, and overall utility of genetic information in the development of recovery plans in animal species is presently unknown.

In this paper we examine the use of genetic data in recovery plans for endangered and threatened animal species in the US, with the goal of providing a broad overview of genetics in the US recovery planning process. Our analysis makes use of a database on recovery plans compiled in conjunction with the National Center for Ecological Analysis and Synthesis (NCEAS), the Society for Conservation Biology (SCB), and the US Fish and Wildlife Service (FWS), as described by BOERSMA et al. (2001), CLARK et al. (2002), and HOEKSTRA et al. (2002). The data were gathered using a survey developed jointly by SCB and USFWS; the database contains information on 181 endangered species complied from 136 recovery plans, drafted or revised during the period 1977 through 1998, and approved by the USFWS or the National Marine Fisheries Service (NMFS). For a description of the types of questions asked in the survey, see HOEKSTRA et al. (2002). The entire database can be accessed at http://www.nceas.ucsb.edu/recovery/. From this sample of surveyed recovery plans, we focus on the presentation and use of genetic data for the conservation of animal species. Given the controversy over the relative utility of genetic versus demographic data, we begin by comparing the use and proposed collection of genetic and demographic data in recovery plans. We then determine how frequently and in what cases genetic factors are cited as threats to species persistence, and how plans respond to these perceived threats. Our goal is to assess the current status of genetics in US recovery plans, in order to better inform both managers and academics of the actual, and potential, uses of genetics in this fundamental conservation context. Although similar reviews of the role of genetics in the conservation of plant species in the USA and Australia can be found in SCHEMSKE et al. (1994) and PEAKALL & SYDES (1996), respectively, to our knowledge quantitative analyses of a large sample of recovery plans for species from a broad range of animal groups (mammals, birds, fish / reptiles / amphibians, invertebrates), are not presently available.

Methods

Data preparation

Eliminating data pertaining to plant species produced a reduced database containing information on 96 animal species from 90 endangered species recovery plans. To evaluate information presented in recovery plans, we identified survey questions in the database that specifically pertained to genetic and demographic data, and genetic threats, and coded these survey responses as binary data (variables of 0 and 1, reflecting yes or no for a given question in the plan under consideration), prior to analysis. In cases where multiple questions from the survey were relevant to a single analysis, we combined these questions and recoded data as a binary response of 1 if the survey indicated that, for any of the appropriate survey questions, the answer was yes, or 0 otherwise, for each plan under consideration.

Statistical analysis of the data consisted of likelihood ratio chi–square tests, performed using the PROC FREQ procedure of SAS (SAS Institute, 1997). The categories compared in analyses are described below (see also tables 2, 3, and 4 in results). Note that because recovery plans were of two types —multispecies plans (where multiple listed species are addressed in the same plan) and single–species plans— it can be difficult to determine the relevant unit of replication for statistical analysis. Accordingly, for questions related to whether species–specific data is presented or requested, or whether genetic threats such as inbreeding are associated with species characteristics (*i.e.*, taxonomic group, range size), we analyzed data on the species level. Most of our analyses were at the species–level. However, for questions related to whether specific recovery tasks were proposed, we analyzed our data at the level of individual plans; this is because whether or not specific recovery tasks are assigned is not likely to be independent for two species in the same recovery plan. Thus for plan–level analyses, we reduced survey data from multi–species plans in the following conservative manner. If there was any positive response for any of the species included in a given multi–species recovery plan, we gave that plan a score of 1; for example, if the database indicated that a recovery task had been proposed for at least 1 species in a multi–species plan, we coded the entire recovery plan as having proposed that particular recovery task.

Specific analyses

What is the relative prominence of genetic vs. demographic data in recovery plan development?

To address this question, we determined what information was presented about each endangered species, and then compared the percentage of plans that included genetic or demographic information. We also examined whether the presented data were qualitative or quantitative in nature, whether there were explicit requests for additional data on genetic and demographic topics, and whether the use of, and specific responses to, this data differed for genetic versus demographic information. Finally, we evaluated whether inclusion of genetic or demographic data was associated with species taxonomic group by analyzing the frequency of plans that included or called for genetic or demographic data within 4 broad taxonomic groupings (mammals, birds, fish / reptiles / amphibians, and invertebrates). Fish, reptiles, and amphibians were combined into a single general category to ensure sufficient sample sizes for statistical analysis. These analyses were performed on the species level.

When are genetic factors viewed as a threat, and how do plans respond to genetic threats?

We analyzed how frequently genetic inbreeding or bottlenecks were viewed as a threat to species persistence and whether citing genetics as a threat was associated with certain species characteristics. Specifically, we analyzed the frequency of plans that cited genetic factors as a threat for 4 broad taxonomic groupings (as outlined above), as well as for species range (*i.e.* restricted (< 1 km^2) versus limited (< 100 km^2) versus widespread (> 100 km^2); as defined in the survey) and for number of extant populations (one population only vs. more than one population). The goal in the latter two analyses was to evaluate whether genetic threats are more likely to be identified when theory predicts species will be most vulnerable to processes of genetic erosion, *i.e.* where species range or number of populations is extremely restricted (*e.g.* Ellstrand & Elam, 1993). Because these analyses sought to determine associations between genetic threats and species–specific characteristics, these analyses were also performed with species level data.

To examine plan responses to perceived genetic threats, we asked whether plans that cited genetic threats were more likely to call for more genetic information, or to propose the specific recovery tasks of captive breeding, translocation and/or reintroduction —all tasks that may alleviate such threats. These analyses were performed at the plan level.

Results

What is the relative prominence of genetic vs. demographic data in recovery plan development?

Recovery plans presented considerably more demographic than genetic data. Some form of demographic data was presented in 79 % of the recovery plans, whereas only 25 % presented genetic information (table 2). In plans in which data were presented, demographic data were more quantitative than genetic data (table 2). Plans were also more likely to call for additional demographic data, in comparison to genetic data (table 2).

Species taxonomic group influenced the likelihood that plans presented demographic data but had no discernable influence on presentation of genetic data (table 3). For demographic information, this difference appears to be driven by the fact that 100 % of mammal plans presented some demographic data whereas these

Table 1. Definitions of terms related to US Endangered Species recovery plans, as used in the text (adapted from STINCHCOMBE et al., 2002)

Tabla 1. Definición de términos relacionados con planes de recuperación de especies en peligro de extinción de Estados Unidos, tal como se emplean en este documento (adaptadas de STINCHCOMBE et al., 2002).

Term	Definition
Data collection	The collection of any information on the population or species; in contrast to Monitoring
Monitoring	Taking direct measures of a population or species to determine if recovery is occurring; in contrast to data collection
Recovery criteria	Criteria or requirements that must be fulfilled to down–list or de–list the endangered species or population
Recovery task	A list of specific activities designed to promote recovery of the species. A list of recovery tasks is contained in the Implementation Schedule of every plan
Task priority	Implementation priority assigned to each recovery task. Recovery tasks are ranked on a scale of 1–3, with 1 being "high priority" in our usage

Table 2. Prominence of genetic versus demographic information in recovery plans: information presented for species. Degrees of freedom for likelihood ratio tests were 1 for each test.

Tabla 2. Importancia de la información genética en comparación con la demográfica en los planes de conservación: la información está organizada por especies. Los grados de libertad en el test del cociente de probabilidad fueron de 1 para cada test.

Were there differences between genetics and demography in terms of...	Answer χ^2 p–value	Category	Genetic information	Demographic information
...proportion of plans presenting this information?	Yes $\chi^2 = 59.6$ $p < 0.0001$	Presented Not presented	25 % 75 %	79 % 21 %
...the kind of information presented?	Yes $\chi^2 = 17.94$ $p < 0.0001$	Qualitative Quantitative	64 % 36 %	19 % 81 %
...calls / requests for additional information?	$\chi^2 = 5.96$ $p = 0.015$	Yes Requested Did not request	41 % 59 %	60 % 40 %

data were available in less than 60 % of invertebrate plans. In the case of every taxonomic group, however, the majority of plans presented demographic data but did not present genetic data (table 3). Assuming that all available information was presented in the recovery plan, results also suggest that birds, mammals, and invertebrates are particularly poorly described genetically (all with < 20 % of plans presenting genetic data), in comparison to reptiles/fish/amphibians where more than twice as many plans presented genetic data. (For contrast, plans drafted for endangered plants presented demographic and genetic data in 72 % and 31 % of plans respectively —Moyle, unpubl. data). Regardless, invertebrates appear to be poorly described for both genetic and demographic data.

With respect to assignment of specific recovery tasks, plans were more likely to assign tasks to monitor demographic than genetic parameters (table 4). The plans that assigned monitoring tasks were significantly more likely to indicate how

Table 3. Prominence of genetic versus demographic data in plan development according to species taxonomic group.

Tabla 3. Importancia de los datos genéticos en comparación con los datos demográficos en el desarrollo de los planes según el grupo taxonómico de la especie.

		Was taxon associated with availability / presentation of…					
		…genetic data?			…demographic data?		
		Answer	χ^2	*p*–value	Answer	χ^2	*p*–value
		No	$\chi^2 = 6.08$	$p = 0.11$	Yes	$\chi^2 = 13.97$	$p = 0.003$
Freq. plans with data	Birds		16 %			84 %	
	Herps / Ichs		41 %			78 %	
	Invertebrates		19 %			57 %	
	Mammals		17 %			100 %	

Table 4. Tasks assigned to monitor genetic versus demographic data, and use of and responses to these data (Plan–level analyses).

Tabla 4. Estudios de análisis de los datos genéticos en comparación con los datos demográficos y su posterior uso y respuestas a estos datos (análisis a nivel de Plan de recuperación)

Were there differences between genetics and demography in terms of…	Answer χ^2 *p*–value	Category	Genetic data	Demographic data
…whether recovery tasks were assigned to monitor this kind of information?	Yes $\chi^2 = 23.93$ $p < 0.0001$	1+ tasks no tasks	20 % 80 %	56 % 44 %
…whether the use of monitored data was specified?	Yes $\chi^2 = 9.35$ $p = 0.002$	analysis specified no anal. spec.	13 % 87 %	32 % 68 %
…whether specific responses to monitored data were noted?	No $\chi^2 = 0.74$ $p = 0.39$	response noted no response	29 % 71 %	19 % 81 %

demographic data would be analyzed than genetic data (table 4); < 15 % of plans proposing to monitor genetic data specified how this data was to be analyzed (table 4). Interestingly, less than one third of plans that proposed monitoring of data in either category also indicated how this new data would change the recovery plan (table 4).

When are genetic factors viewed as a threat, and how do plans respond to genetic threats?

Of 96 species that had data available, 22 % of plans cited genetics (*i.e.* inbreeding depression or genetic bottlenecking) as a threat to species persistence. Of these, 65 % identified this threat as anticipated, while fewer plans (50 % of those with data available) identified the genetic threat as extant / current (as classified in the plan survey). Identification of genetics threats did not differ statistically between taxonomic groups, although approximately one third of plans drafted for birds and mammals identified genetic factors as a threat, whereas approximately half as many plans for invertebrates and reptile / fish / amphibians did so (table 5). Estimated species range and number of populations did not influence whether genetic factors were cited as a threat (table 5), indicating that perceived genetics threats are not limited to those circumstances where theory suggests species

Table 5. Associations between genetic threats to species persistence and species–level characteristics.

Tabla 5. Relación entre las amenazas genéticas para la supervivencia de una especie y las características de la misma.

Is citation of genetics as a threat associated with...	Answer χ^2 *p*–value	Category	Frequency of plans citing genetic threats (n / N)
...taxonomic group?	No	Birds	32 % (7 / 22)
	$\chi^2 = 3.79$	Herps / Ichs	16 % (5 / 31)
	df = 3, $p = 0.29$	Invertebrates	14 % (3 / 21)
		Mammals	33 % (6 / 18)
		Total	22 % (21 / 92)
...species range?	No	Restricted (< 1 km^2)	15 % (2 / 13)
	$\chi^2 = 2.54$	Intermediate (< 100 km^2)	11 % (2 / 17)
	df = 2, $p = 0.28$	Broad (> 100 km^2)	28 % (13 / 46)
		Total	22 % (17 / 76)
...number of populations?	No	One population	17 % (6 / 36)
	$\chi^2 = 0.545$	> one population	25 % (10 / 40)
	$p = 0.460$	Total	21 % (16 / 76)

will be most vulnerable to processes of genetic erosion (*i.e.* single extant population and/or extremely restricted species range).

Plans that cited genetics as a threat were no more likely to call for more genetic information than plans that did not identify genetic threats, but were more likely to propose an explicit recovery task to monitor genetic information (table 6). Nonetheless, citing genetics as a threat did not influence whether these recovery tasks were given highest (*i.e.* priority 1) versus secondary (priority 2 or 3) implementation priority (table 6); indeed, recovery tasks dealing with genetic threats were almost always assigned the highest priority (table 6) without regard to whether genetics was explicitly cited as a threat or not.

Finally, we found mixed evidence that plans that cited genetics as a threat proposed specific recovery tasks that can alleviate those threats, *i.e.* captive breeding, reintroduction, and/or translocation. Recovery tasks involving reintroduction into new or formerly occupied habitat were associated with identification of genetic threats, however tasks involving captive breeding and translocation of individuals were not (table 6).

Discussion

In general, despite the prominence of genetic factors in the rescue and recovery of specific endangered animal groups (*e.g.* Westemeier et al., 1998; Madsen et al., 1999; Vila et al., 2003) genetics appears to have played a limited and ill-defined role in the US recovery planning process to date, certainly one that appears incongruent with current academic interest in conservation genetics. First, our results indicate that demography is consistently better represented and emphasized than genetics in endangered species recovery plans. This greater emphasis on demographic information agrees with the prescriptions of some conservation biologists (*e.g.* Lande, 1988; Caughley, 1994) who maintain that, for critically endangered species, genetic data is unlikely to be as informative or valuable as demographic data in assessing biological status or determining appropriate management strategies. Our findings suggest that recovery plan managers do in fact rely more heavily on demographic parameters for these purposes. Nonetheless, we also found that genetic factors are in fact cited as threats in a substantial minority (22 %) of recovery plans, but that individual plan responses to these perceived threats are neither uniform nor consistent. In addition, our results indicate that recovery plans often do not contain a clear articulation of how genetic data can be used effectively to address the recovery of endangered species; for example, less than one-third of plans that proposed monitoring genetic parameters indicated how new data would change the recovery plan. Overall, our results suggest that there is a limited understanding of how genetics can be used to aid in species recovery, even in cases where genetic factors are explicitly identified relevant to species persistence and recovery.

Our first major finding agrees qualitatively with prior surveys in plant species recovery plans that similarly found a discrepancy between demographic and genetic information. In particular,

Table 6. Associations between perceived genetic threats to species persistence and recovery plan responses to genetic threats.

Tabla 6. Relación entre las supuestas amenazas genéticas para la supervivencia de una especie y las respuestas de los planes de recuperación a esas amenazas genéticas.

Does the recovery plan…		Cite genetics as a threat? Yes (n / N)	No (n / N)	Significant association? χ^2, p–value
...request further genetic information?	Yes	27 % (6 / 22)	17 % (11 / 64)	No
	No	73 % (16 / 22)	83 % (53 / 64)	$\chi^2 = 0.99$, $p = 0.32$
...propose a matching recovery task?	Ye	64 % (14 / 22)	10 % (6 / 62)	Yes
	No	36 % (8 / 22)	90 % (56 / 62)	$\chi^2 = 23.95$, $p < 0.0001$
...assign high priority to the proposed recovery task?	Highest priority	93 % (13 / 14)	83 % (5 / 6)	No
	Secondary priority	7 % (1 / 14)	17 % (1 / 6)	$\chi^2 = 0.39$, $p = 0.53$
...propose a captive breeding task?	Yes	67 % (14 / 21)	47 % (30 / 64)	No
	No	33 % (7 / 21)	53 % (34 / 64)	$\chi^2 = 2.52$, $p = 0.11$
...propose a translocation task?	Yes	38 % (8 / 21)	39 % (24 / 62)	No
	No	62 % (13 / 21)	61 % (38 / 62)	$\chi^2 = 0.002$, $p = 0.96$
...propose reintroduction into former habitat?	Ye	86 % (18 / 21)	58 % (37 / 64)	Yes
	No	14 % (3 / 21)	42 % (27 / 64)	$\chi^2 = 5.99$, $p = 0.01$
...propose reintroduction into new habitat?	Yes	37 % (7 / 19)	15 % (9 / 59)	Yes
	No	63 % (12 / 19)	85 % (50 / 59)	$\chi^2 = 3.75$, $p = 0.051$

Schemske et al.'s (1994) survey of 98 USFWS plans for individual plant species (draft dates ranging from 1980 to 1992) found fewer than 8 % of plans presented detailed genetic information whereas detailed demographic data were presented in 33 % of all such plans. They also found that collection of additional demographic information was proposed for 84 % of plans, but only 26 % proposed additional genetic studies, similar to our findings for animal groups. By contrast, Peakall & Sydes (1996) reported that, for the Australian state of New South Wales, 57 % of all plant recovery plans they reviewed recommended inclusion of genetic studies in the recovery program. Quantitative discrepancies in the frequency of data presented between our analysis and the other US study may be due to divergent definitions of data (*i.e.* our plan survey did not require that presented data be detailed); however, the difference in historical coverage between the two studies is likely more important. In particular, Schemske et al.'s (1994) analysis —of plans from 1980 to 1992— captured fewer recent recovery plans than our survey. Elsewhere we have shown that more recently drafted US recovery plans (*i.e.* post–1995) are significantly more likely to assign monitoring, management, and recovery tasks to genetic factors than older (pre–1995) plans (Stinchcombe et al., 2002), indicating that genetics receives more attention in more recently drafted, versus older, recovery plans. In comparison to Schemske et al. (1994), we found that more plans presented genetic data overall, which is consistent with this apparent trend to increased consideration of genetics in more recent plans. Conversely, note that the difference in taxonomic coverage (*i.e.*, plants *vs.* animals) between the two analyses is unlikely to explain qualitative differences in the amount of genetic and demographic data presented, because plans written for plants in our database showed similar results to our findings for animal groups (Moyle unpubl. data). The discrepancy between available data for genetics and demography was also observed within each of animal taxonomic group analyzed individually. Regardless, it is clear that —of all 4 taxonomic groupings— invertebrates are very poorly understood both genetically and demographically, suggesting a particular need for more basic biological research on endangered species within this animal group. Birds and mammals also appear to be poorly described genetically; although the reasons for this are unclear, it may be that for mammals and birds generally, other biological information (*e.g.* historical ranges /

abundances, demographic data) is frequently available such that information on genetics may less frequently (or consistently) be collected and / or included in recovery plans.

Our findings on the relative prominence and use of genetic versus demographic data are not altogether surprising. Given the relative ease with which some kinds of demographic data (*e.g.* birth and death rates for sessile organisms, or clutch / litter size / seed production) can be collected in comparison to data on genetic diversity, inbreeding depression or gene flow, one might expect demographic data to be more abundant. In addition, the relative youth of conservation genetics and confusion stemming from the controversial debate about its importance in the persistence and recovery of endangered and threatened species (*e.g.* LANDE, 1988; CAUGHLEY, 1994; FRANKHAM, 1995; PEAKALL & SYDES, 1996; HEDRICK & KALINOWSKI, 2000), might also be acting to limit the collection and application of genetic data in recovery plans.

Nonetheless, the second major finding of our analysis —that genetic factors are identified as threats to species persistence in a substantial minority of animal recovery plans— indicates that explicit consideration of genetic factors in species recovery planning is of more than purely academic interest. That genetic recovery tasks are almost always assigned highest priority underscores this recognition that genetic factors can be of real practical concern in the recovery of individual endangered species. Accordingly it is a genuine concern that, while there is good information available on the potential longer–term management and utility of genetic variation (*e.g.* SCHONEWALD–COX et al., 1983; LANDWEBER & DOBSON, 1999), much of this work is failing to be translated into effective recovery strategies within the US recovery plan conservation process (see also STINCHCOMBE et al., 2002). Indeed, our findings generally support SCHEMSKE et al.'s (1994) suggestion that much genetic research that is proposed in recovery planning might be motivated by the hopeful search for limiting factors or ongoing threats to species, rather than by a clear vision of its utility in developing recovery objectives or facilitating recovery efforts. If genetics continues to increase in prominence in recovery plans (STINCHCOMBE et al., 2002), this failure will become an increasingly large liability in the recovery planning process.

Overall, our results suggest that the most pressing need of recovery managers with respect to conservation genetics is simple, concise and transparent guidelines as to contexts in which genetics can provide unique and useful information in the development and management of endangered species recovery. Fortunately, researchers have already begun to develop such guidelines. For example, in the case of plant species, PEAKALL & SYDES (1996) suggest that collection of genetic data will be most appropriate in four specific contexts. These are where: (i) it is not possible to conserve all available populations and/or reserve design is a management option; (ii) translocation or *ex situ* programs are prescribed; (iii) species may be extensively clonal or inbreeding; and, (iv) taxonomy is uncertain. In these cases, genetic data may offer unique insight into determining which units to preserve or use as source material, beyond that which is provided by other (*e.g.* demographic) types of data. For example, additional genetic data is more likely to provide unique management information where species occur in multiple extant populations that cannot all receive conservation attention; in contrast, for species limited to a single extant population genetic data may be less useful because demographic information already suggests that preserving individuals in the single remaining population is the highest recovery priority (PEAKALL & SYDES, 1996). Similarly, all other things being equal, species whose populations occur primarily on land that is already protected are less likely to benefit from additional genetic information than species for which land acquisition for protection remains a pressing issue. (We are not suggesting that taxa located primarily on protected lands are not in need of active management or additional research; merely that, on average, genetic data is likely to be more useful when there are decisions to be made about populations that are not yet formally protected.)

Given these wholly pragmatic considerations, we expect that in general genetic information will provide unique information in instances where the species occurs in more than one population, and/or where decisions must be made about which (currently unprotected) populations to preferentially preserve. Genetics can also play a unique role in determining which individuals most warrant protection, via genetic investigations of relatedness and/or taxonomic ambiguity (as well as, in the case of plants, potential clonality), in addition to making management decisions about intense manipulative conservation efforts (*e.g.* captive breeding programs, reintroductions). In this way, rather than evaluating the utility of additional genetic data on the basis of predictions arising from genetic theory, genetics should be assigned a role in recovery planning based on whether it is likely to provide unique information on management strategies or options, beyond that provided by demographic and other data. As such, in the future it may be useful for recovery plans to integrate current guidelines as to the best use of genetic data (*e.g.* PEAKALL & SYDES, 1996) directly into the recovery planning process. Such rules of thumb will provide greater guidance as to the utility of collecting genetic data, particularly in the absence of any other relevant information, and would help clarify how such data is to be used to inform and modify recovery efforts. This would minimize resources wasted on uninformative research, while maximizing the utility of genetic data in contexts where it can provide unique insight into current and future management strategies. It should be clear that we are not advocating that less effort be put into the consideration of genetics of endangered species, but rather that more effort be devoted to considering how and when such information is most useful in urgent management situations, such as recovery efforts.

Finally, we believe this can best be achieved through further strengthening links between the academic and applied conservation communities. In particular, the onus is on academic conservation biologists (particularly conservation geneticists) not just to develop more pragmatic guidelines as to the best practical use of genetics in conservation contexts, but also to be more directly involved in the recovery planning process itself, especially by serving on recovery planning teams. Recovery plans that do include at least one academic scientist as an author articulate a much clearer use of biological information in the design of monitoring strategies, and tend to show a clearer use of biological information in the selection of recovery criteria (GERBER & SCHULTZ, 2001), indicating that academic involvement in recovery planning can improve the utilization of biological information. Of all plans in the database analyzed here, however, only 5 % were authored by academic scientists, and only one third of recovery planning teams included academic scientists as members (Stinchcombe, unpubl. data). In addition, the participation of academic scientists as plan authors or in recovery planning teams did not increase in the period covered by the database (GERBER & SCHULTZ, 2001; Stinchcombe, unpubl. data), indicating there is considerable room for improvement in academic participation in the planning process. The USFWS has recently adopted new policy to formally encourage increased diversity within recovery planning teams (CLARK et al., 2002). It is now up to academic scientists to respond positively to this conservation need.

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