How to bring genetic diversity to the forefront of conservation policy and management

Sean M Hoban, Heidi C Hauffe, Sílvia Pérez-Espona, Giorgio Bertorelle, Katie Frith, Oscar Gaggiotti, Peter Galbusera, A Rus Hoelzel, Richard Nichols, Craig Primmer, Gernot Segelbacher, Hans R Siegismund, Marjatta Sihvonen, Critiano Vernesi, Carles Vilà, the ConGRESS Consortium*, and Michael W Bruford

*José Godoy, Pim Arntzen, Isa-Rita Russo, Josef Bryja

INTRODUCTION

The contribution of genetic diversity to the maintenance of species and habitat diversity (Struebig 2011), and to fundamental ecosystem processes (e.g. pollination, decomposition, soil fertility; Hughes et al. 2008) is now widely recognized by the conservation community. Genetic diversity is also appreciated as an essential component of ecosystem resilience and the capacity for species to adapt in changing and challenging environments (Sgro *et al.*, 2011). Furthermore, genes from adapted wild populations can contribute desired traits (e.g. drought tolerance, disease resistance) to cultivated plants and livestock, helping to reduce conventional inputs (e.g., irrigation, chemical pesticides) and ensure long-term food security. Genetic resources also contribute billions of dollars to pharmaceutical and biotechnology industries. However, it is estimated that genetic resources are being depleted by 2-4.5 trillion US dollars/year globally (ten Brink et al. 2009). The message is clear: if sufficient within-species genetic diversity is not conserved, the ecological and economic effects will be widespread and catastrophic.

In recognition of the importance of the genetic component of biodiversity, the Convention on Biological Diversity has for the first time included consideration of genetic diversity with the Aichi Targets, in the 2010 revised Strategic Plan for Biodiversity (http://www.cbd.int/sp/). Specifically, Target 13 states that, by 2020, (1) "*the genetic diversity of cultivated plants and farmed and domesticated animals and of wild relatives, including other socio-economically as well as culturally valuable species is maintained",* and (2) "*strategies have been developed and implemented for minimizing genetic erosion and safeguarding their genetic diversity*." It is a bold, explicit goal to minimize near-term loss as well as put in place plans to ensure genetic variation is secure for the future. While the target primarily emphasizes domesticated species, its wording could and should be interpreted to also require conservation of genetic resources of any species providing benefits to humans via cultural, provisioning, recreational, or other ecosystem services, or species that helps ensure the stability or resilience of natural systems intimately connected to human society. Achieving these objectives will require an array of *in-situ* and *ex-situ* conservation initiatives such as habitat restoration and managing exposure to selection (Lankau *et al.*, 2011), and achievable targets and indicators for measuring progress. Genetic tools, which can rapidly obtain various ecological information, will surely serve multiple Aichi targets (Santamaría & Méndez 2012).

Designing, executing and monitoring appropriate actions to preserve and protect genetic biodiversity will in turn require a stronger foundation of genetic knowledge and capabilities among all parties, a foundation that is currently weak. Indeed, Frankham (2010) highlighted insufficient genetic training of decision makers as a major challenge in conservation genetics today (though knowledge varies extensively among countries). At minimum, decision-makers should have knowledge regarding the value of genetic biodiversity, basic genetic topics and concerns, what questions genetic tools can and can't answer, and how to access more information and form partnerships. Clear, practical and engaging dissemination of well-established genetic tools and topics, and their applications in conservation biology, is prerequisite to sound policy and management. Equally, conservation genetics experts and translational researchers should understand and participate in policy-making processes, and offer direct support to managers (Osmond *et al.*, 2010), but this connection is rare. Of 1646 articles published in the journal Conservation Genetics since its inception in 2000, 408 (24.8%) contained the term "management" and a scant 13 (0.8%) mentioned "policy."

Several recent initiatives (the United States Fish & Wildlife Service Genetic Monitoring for Managers http://alaska.fws.gov/gem/mainPage_1.htm, the Knowledge Exchange Project http://www.shef.ac.uk/aps/research/ke, and the Conservation Genetic Resources for Effective Species Survival Project, ConGRESS, http://www.congressgenetics.eu) address the challenge to facilitate application of knowledge from past and present conservation genetic research. These initiatives recognize that for many situations we already have sufficient genetic data to make specific recommendations, that much important knowledge has not been made accessible beyond the scientific community, and as a consequence, decisions and policies are not based on the best available information. Better interpretation, presentation, and integration are needed (knowledge mobilization), but this cannot be accomplished by a review article or book written with only the scientific community in mind. To reach policy makers and managers, material must be interactive, attractive, participatory, and in non-technical language. These efforts use multiple vehicles to share information including simple, narrative explanations of fundamental genetic processes; accessible definitions for technical vocabulary; suggestions as to when conservation genetics may and may not be useful for conservation problems (including case studies); practical tools for making decisions using genetic data; and most importantly, forums and contact-lists to encourage partnerships between researchers and non-researchers. Such partnerships are envisioned as flexible networks that embrace the views and needs of local stakeholders and decision makers, and promote bidirectional learning (Smith *et al.*, 2009). These features distinguish several emergent biodiversity networks: the US Fish & Wildlife Conservation Genetics Community of Practice (http://www.fws.gov/ConservationGeneticsCOP/), the European Union Biodiversity Knowledge Network (http://www.biodiversityknowledge.eu/), and the European Wildlife Network (http://europeanwildlife.net/). The goals of such communities are to establish communication links, broaden perspectives, facilitate information exchange and training, ensure that diverse interests are represented, and identify and bridge knowledge gaps. In doing so, these initiatives facilitate Aichi Target 16, a mandate that genetic resources benefits can be accessed and fairly shared by all, and Target 19, which mandates broad sharing and application of biodiversity knowledge.

A challenge that such efforts face is that knowledge-sharing and capacity-building must be focused and efficient in synthesizing and simplifying knowledge in a way that non-academic parties can absorb and use (Osmond *et al.*, 2010). Generally, policy makers and managers are not and do not want to be geneticists. In general, they are unable to intensively read the scientific literature (Laurance *et al.*, 2012), due to scientific terminology, time constraints, and difficulties in finding and accessing appropriate publications. Thus in spite of a wealth of data generation from geneticists, much important data is dispersed, inaccessible or misunderstood. Within Europe, a further challenge is varying needs and priorities among many nations, which makes efforts to find common ground especially important.

SURVEY

Given current policy-drivers and emerging opportunities and challenges for the use of genetics in conservation, an assessment of the current state of applied conservation genetics is timely. Focal questions include: What is the current level of knowledge, capabilities, and interests of managers, and what actions are being performed? What are key topics and concerns to which conservation geneticists should focus to make scientific results usable, and possibly direct future research? To assess genetic knowledge and application in European biodiversity conservation, ConGRESS distributed a simple questionnaire during 2010 and 2011, receiving 131 responses from ten nations (Belgium, Spain, Finland, France, Germany, Italy, Netherlands, Portugal, Sweden, UK), covering governmental and non-governmental organizations, with a range of experience and education. This was not a systematic survey, and may suffer some bias in the returns. We use survey results to discuss some current directions, challenges and opportunities for the European conservation genetics community.

The first question assessed the current reach of conservation genetics, relative to its potential. We found that almost half of respondents (42%) had never participated in, used data from or commissioned a genetic study. However, nearly all respondents (94%) would use genetic information if they perceived that it was available to them. We can infer that, in spite of only moderate incorporation or consideration of genetic data up to now, there is a high level of interest in, and recognition of, its potential utility in conservation decision-making. Therefore, while genetics has only very recently been a primary consideration in policy at the European and global level, individual practitioners are aware of its importance and anticipate using genetics if tools, funding, and partnerships are made available.

Respondents who had implemented or commissioned a conservation genetics project, were asked to specify the study topic. Three main topics were identified (c. 40% of responses): 1) identifying units for conservation (15%), 2) monitoring individuals and populations over time (11%, including invasive species), and 3) species identification and clarification (13%). The popularity of these topics may relate to their relevance to EU policy directives, among other reasons. The first two are applications that can strongly contribute to selection and maintenance of Natura 2000 sites, the European network of nature conservation areas (http://ec.europa.eu/environment/nature/natura2000/) which conservation managers have been involved in identifying. The second and third are relevant to protecting and monitoring particular species as specified under Articles 11, 12 and 13 of the Habitats Directive (http://ec.europa.eu/environment/nature/legislation/habitatsdirective/). Species identification also contributes to policing actions, such as enforcing CITES (the Convention on International Trade in Endangered Species, http://www.cites.org/). Thus there appears to be a good match between the current most common uses of genetics in management and relevant directives, implying that these topics can be directly used in the current policy arena. Another likely reason for the popularity of these topics is that they have a large empirical and theoretical body of work, and increasingly powerful and practical molecular and statistical tools for clarifying species boundaries; monitoring and assessing genetic biodiversity with ancient samples, environmental DNA, and DNA barcoding; and prioritizing populations for protection.

The next most common topics reported by respondents who had applied genetics to their conservation projects were those of quantifying population size (6%), measuring inbreeding (4%), connectivity (7%), and hybridization (5%). Such questions focus on population vulnerability, and response to recent environmental changes. A substantial interest in these topics suggests that practitioners understand that genetics concerns affect population and species' viability, and this in turn may reflect recognition of the importance of long-term population viability for determining 'favorable conservation status' (FCS), a central concept in the biodiversity legislation of the European Union (Laikre *et al.*, 2009). Viability and connectivity are topics that managers and policy makers may be already familiar with, so they represent easy "entry points" for networking.

Several less frequently reported topics included assignment/parentage (4%) and local adaptation (1%), indicating that some practitioners are already aware of and using specific and technical applications, sometimes including recent molecular advances. This awareness may provide collaboration opportunities; practitioners that are already experienced in genetics could be key partners in recruiting and teaching others. Some managers and policy makers will be more familiar with conservation genetics as a tool rather than a concern, while others may have the opposite experience. This provides a potential opportunity to show that powerful genetic tools can reveal a wide variety of ecological information (Frankham 2010). For less common topics and tools it may be especially important to use case studies to illustrate the importance of the issue and the solutions that genetic tools provide.

The second question concerned potential future uses of genetics. Responses largely overlapped with current uses, with similar emphasis on identifying conservation units, monitoring, and species identification but a greater emphasis on assessing habitat connectivity. A challenge here is to maintain and enhance awareness of emerging tools (e.g., ancient and environmental DNA, genomics, simulation software), and demonstrate applications and case studies, while simultaneously avoiding information-overload. It is also important to reiterate that general measurements of genetic diversity (e.g. differentiation levels) are a first step in other applications (e.g., population assignment, forensics, certification), emphasizing the need to adequately organize, archive and share samples and data for future projects. Another emerging use of genetics is to establish baseline genetic diversity measures against which future comparisons can be made to demonstrate decline or recovery (Jackson et al. 2011).

DIRECTIONS

We now discuss some overall challenges and opportunities regarding genetic tools, partnerships, and applications.

Genetic tools

One challenge in connecting conservation genetic tools and topics to management and policy is to explain the power and utility of highly technical tools, while simultaneously promoting and ensuring proper use. What can be done? First, it is important to clearly delineate what genetics tools and techniques can and cannot do for conservation management, to avoid making promises beyond our capabilities, while highlighting instances of good practice. In addition, scientists can organize training workshops for those without experience in genetics who wish to begin genetic-based studies (Anthony *et al.*, 2012). Next, case studies can be used to help practitioners understand the process of applying a genetic tool to a management objective (*sensu* Weeks et al 2011). Then geneticists can promote proper use by sharing cautions and suggestions, such as the NCEAS/NESCent Working Group on Genetic Monitoring sampling guidelines (Jackson et al. 2011). To do so, it is important to delineate appropriate sampling schemes and other requirements to obtain relevant data, such as by evaluating tools and techniques with simulations and empirical data (Hoban *et al.*, 2012). As Frankham cautions, "*the burgeoning development of methods has outstripped the quality control processes*."

At the same time, conservation geneticists should recognize the activities, needs, and pressures of practitioners, which may not match our perceived priorities. What is academically exciting (e.g., cutting-edge technology) will not always have high practicality or necessity. Further, the role of the conservation geneticist and the manager of natural resources are different. Conservation geneticists may aim to understand population dynamics and risks, but managers will make and implement decisions, balancing various practical concerns. In explaining and recommending genetic methods, scientists might consider focusing on study avenues that have a high benefit/cost ratio.

Partnerships

We suggest closer and more constant collaborations with local managers, from sourcing research questions to interpreting results to clearly translating results into specific applications

(Knight *et al.*, 2008). Geneticists can also help in reviewing project proposals and reports, and evaluating post-project success. These consultancies would be relatively simple for genetics experts, would save public spending on projects by ensuring optimal design and interpretation, and would build trust and partnerships between academics and practitioners (possibly leading to collaborations that are mutually beneficial). Each collaborator or stakeholder maintains his/her expertise while learning and profiting from the other (complementary expertise, shared samples and funds, publicity). Networking is needed not only between scientists and managers, but also among in-situ and ex-situ conservationists for integrated species management (Lacy, 2012). One requirement to achieve fruitful partnerships is more flexible timelines and a wider variety of funding mechanisms to match these kinds of investigations (weeks or months to genotype samples for a poaching investigation, many years for monitoring).

As participation in conservation genetics broadens, a concomitant challenge will be to explain basic genetic concepts (e.g., mutation, connectivity) in a simple, memorable manner without complex vocabulary (e.g. the coalescent, Bayesian). In addition, conservation geneticists must accept and confront the fact that disagreements exist about some central conservation genetics topics within the community (Pertoldi *et al.*, 2007), e.g.: the best options for managing hybridization, if and when to use translocations, criteria for selecting protected sites, evolutionary significant units, and what defines a species. Disagreements within the research community about the role of genetics, the solutions it provides, and confidence in the tools are important discussions to advance the field, but scientific debate traditionally makes non-specialists and policy-makers wary or uncomfortable. A key challenge is to emphasize the issues where there is near universal agreement and the tools that have been validated in many cases, while working towards resolving existing disagreements to avoid confusion among policy and management professionals (Frankham, 2010).

Applications

Scientists must also have courage to offer strong, science-based advice, even if it is imperfect. Lankau et al (2011) and Weeks et al. (2011) are two examples of management-directed syntheses of current knowledge combined with practical recommendations. The first provides practical suggestions to incorporate evolutionary thinking in policy and management strategy, especially to enhance and accelerate adaptation to climate change. The second provides a review of evidence regarding translocations, a decision tree to help guide when to apply it, and a set of translocation case studies. They both stress that while desired outcomes may not be assured, the chance of a good outcome can be facilitated with appropriate guidance and tools. Conservation genetic scientists should also examine the potential management and policy implications of their work, especially before beginning a particular study, in order to produce knowledge and understanding that will truly be applied to the issue or species in question. Howes et al. (2009) propose a decision key to assist evaluation of the “conservation merit of genetics research questions,” and demonstrate its use with several case studies.

The main challenge is to spread available knowledge *now*. This requires increased understanding by the conservation geneticist community of the policy-making process, socio-economic issues, and awareness of management resource limitations. If we want the conservation community to consider and incorporate genetics, we as geneticists must appreciate the practical concerns- political, social, and economic. Those members of the conservation genetics community who are able can take initiative to provide consultation services for decision makers, or become directly involved in policy discussions, which may be especially effective at local levels (Smith *et al.*, 2009). Scientific input is also needed at the EU level- Santamaría & Méndez (2012) highlight numerous policies in which genetic aspects could be considered (e.g., the Sustainable Hunting Initiative, reformation of the EU Fisheries Policy). These publicly available proposals are an opportunity to introduce genetic aspects and highlight case studies closely linked to human society (e.g., forensics, zoos, urban species, iconic wild species). As individual action is challenging, another solution is that scientific societies (e.g., Society for Conservation Biology) are increasingly involved in policy discussions, position statements, and funding policy training.

Another instrument for engagement is the systematic review, which identifies and synthesizes all available knowledge relating to a particular research question (examples at http://www.environmentalevidence.org/). Communities like ConGRESS, and larger interface organizations (e.g., http://www.spiral-project.eu/), are also central. Scientists rarely become policy experts but can work and interact with lawyers, political scientists, economists and decision makers (Smith *et al.*, 2009). Also, biologists who are just beginning post-graduate education may enroll in emerging transdisciplinary programs that immerse students in policy, communication, formal logic, ethics/philosophy, and science. Lastly, as academic labs are constrained by funding organization priorities (high impact publications, novel results) and timelines, it is also imperative to create and fund applied conservation genetics laboratories (governmental or non-governmental) whose mandate is to gather, translate and disseminate genetic information about key species and ecosystems. Examples of such efforts include the Molecular Ecology team of the US National Marine Fisheries Service (http://swfsc.noaa.gov/textblock.aspx?Division=FED&id=902), the Institute of Forest Genetics of the US Forest Service (http://www.fs.fed.us/psw/locations/placerville/), the Wildgenes Laboratory of the Royal Zoological Society of Scotland (http://www.rzss.org.uk/research/applied-conservation-genetics), and the Canadian Forest Gene Conservation Association (http://www.fgca.net).

In conclusion, policy makers and managers already possess some awareness of the relevance of genetic concepts and tools in many areas of conservation. Conservation geneticists can become more aware of the policy and management implications of their work by: identifying key genetic issues, considering conservation applications while formulating research questions, forming partnerships in planning and executing projects, and clearly defining the contribution that we expect genetics to make and its connections to other data and issues. An especially open and necessary research direction is to better evaluate the economic and ecological value of genetic resources and define exactly the services that genetic diversity provides to society and the planet (ten Brink et al. 2009), including but certainly not limited to monetary valuation. Of course, integration of genetic benefits into environmental decision-making will require much more extensive theoretical research and empirical quantification of the role of genetics in ecosystem stability, as relatively few examples exist (Cardinale *et al.*, 2012). We may bemoan the fact that genetic information and tools are underused and underappreciated, but they will remain so until we clearly demonstrate their practical application.

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