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Forum

How can biodiversity strategy and action plans incorporate genetic diversity and align with global commitments?

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Abstract

National, subnational, and supranational entities are creating biodiversity strategy and action plans (BSAPs) to develop concrete commitments and actions to curb biodiversity loss, meet international obligations, and achieve a society in harmony with nature. In light of policymakers' increasing recognition of genetic diversity in species and ecosystem adaptation and resilience, this article provides an overview of how BSAPs can incorporate species' genetic diversity. We focus on three areas: setting targets; committing to actions, policies, and programs; and monitoring and reporting. Drawing from 21 recent BSAPs, we provide examples of policies, knowledge, projects, capacity building, and more. We aim to enable and inspire specific and ambitious BSAPs and have put forward 10 key suggestions mapped to the policy cycle. Together, scientists and policymakers can translate high level commitments, such as the Convention on Biological Diversity's Kunming–Montreal Global Biodiversity Framework, into concrete nationally relevant targets, actions and policies, and monitoring and reporting mechanisms.

Keywords: Convention on Biological Diversity, conservation genetics, policy, monitoring, implementation

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The Convention on Biological Diversity (CBD) is a multilateral treaty with 196 Parties (195 countries plus the European Union), in force since 1993, that commits to biodiversity conservation, sustainable use, and equitable sharing of benefits from use of genetic resources. In December 2022, the Parties to the CBD adopted the Kunming–Montreal Global Biodiversity Framework (GBF), setting a roadmap for reversing biodiversity decline by 2030. As a part of the GBF, each Party, including subnational and supranational entities, will update their biodiversity strategies and action plans (BSAPs)—documents that are used to assess, plan, undertake, monitor, and review actions to achieve the goals and targets agreed to under the CBD (CBD/COP/DEC/15/6). National BSAPs (NBSAPs) allow the Parties to articulate national level biodiversity targets and their alignment to the convention's objectives and other national planning initiatives (e.g., South Africa's National Development Plan for 2030). Ideally, NBSAPs should have high-level support from policymakers (e.g., legislators and country leaders) and should be a product of cross-ministerial cooperation (CBD 2022). They also offer an opportunity for codevelopment with communities to foster broad societal ownership and investment in biodiversity. Local and regional authorities are also developing supranational and subnational biodiversity strategies (www.cbd.int/nbsap/related-info/sbsap), such as in 26 Brazilian states and many Brazilian municipalities (Ministério do Meio Ambiente 2017) and in ASEAN (the Association of Southeast Asian Nations; https://beta.aseanbiodiversity.org/action-plans), as are businesses and indigenous groups.

Previous research showed that genetic diversity conservation had been neglected in national reports and planning documents under the CBD (Laikre et al. 2010, Hoban et al. 2021b). Genetic diversity underpins population and species persistence, as well as species and ecosystem diversity, and is essential for nature's resilience in the face of pressures such as climate change (Beger et al. 2014, Kardos et al. 2021, Hoban et al. 2021a, Shaffer et al. 2022). Conserving genetic diversity also delivers social and economic benefits, sustainable resource use, stable food supply, and mitigation of extreme events (Reusch et al. 2005, Hollingsworth et al. 2020, Stange et al. 2021). In adopting the GBF, the Parties committed to maintain, manage, and restore genetic diversity, focusing for the first time on all domesticated and wild species, in Goal A and Target 4 (see figure 1). This is an expanded commitment from the previous 2011–2020 Strategic Plan for Biodiversity, which was focused on conserving genetic diversity in agricultural species, their wild relatives, and other species of socioeconomic importance.

In the present article, we present 10 suggestions (table 1) for how targets and strategies for policies about, actions toward, and reporting about the conservation of genetic diversity can be articulated in BSAPs. While our primary goal is to inform the Parties to the CBD regarding their NBSAPs, we use BSAP because the advice can inform strategies and actions at all levels—national, local, and regional. We aim to provide a general perspective to promote dialogue, inspiration, and starting points for drafting new BSAPs. We illustrate ideas with examples drawn from BSAPs obtained through the CBD's Clearing House Mechanism: all BSAPs published between January 2020 (release of the zero draft of the Global Biodiversity Framework) and February 2024 (Australia, Barbados, Cambodia, China, the European Union, France, the Republic of Ireland, Japan, the Republic of Korea, the Republic of Serbia, Spain, Tunisia), plus earlier time periods to include geographic diversity and a wide range of viewpoints (Algeria, Argentina, Brazil, Colombia, Indonesia, Papua New Guinea, Uruguay) and unofficial draft documents from Sweden and the SADC (the Southern African Development Community). We include examples for both wild and

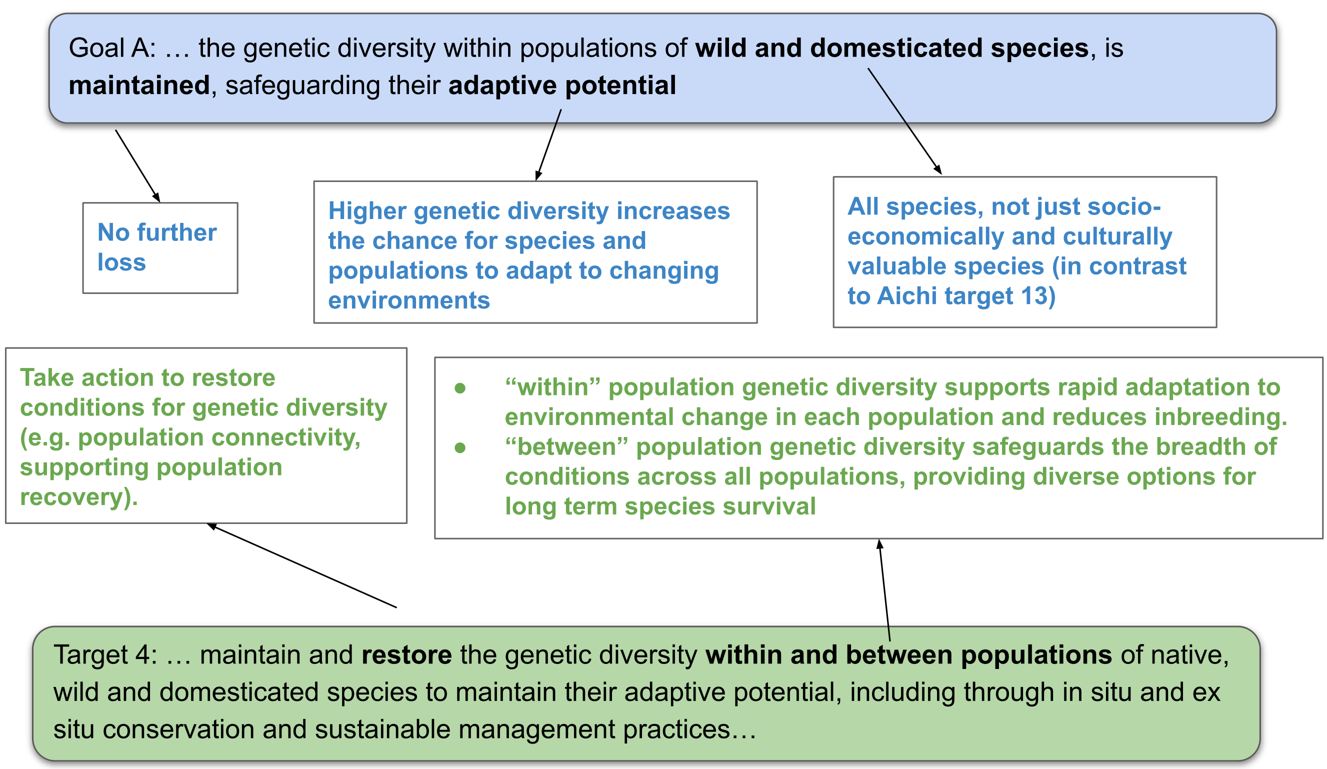

Figure 1. Wording of Goal A and Target 4 of the Kunming–Montreal Global Biodiversity Framework relevant to genetic diversity, with explanations of some key words and phrases relating to genetic diversity (bold with arrows).

Table 1. In order to include genetic diversity in BSAPs, the three parallel phases of policy and CBD guidance should be followed and 10 recommendations considered.

Phase of policy	CBD guidance	Recommendations
Define agenda and impact, adopt policy	Setting national targets	Involve all stakeholders: The BSAP will be more likely to succeed and will deliver wider societal benefits if its development involves inclusive participation and takes a rights-based and whole-of-society approach, in line with section C of the GBF.
		Set a national target on genetic diversity conservation within all species that contain the same components and ambition as the global target: An effective genetic diversity target will be aligned with the global target, which includes maintaining genetic diversity within and between populations of native, wild and domesticated species at sufficient levels for adaptive potential.
		If possible, set national targets that are more ambitious and specific, including means of achievement: Parties can make national targets more ambitious by increasing specificity and scope, and including target components on policy and planning, enabling countries to benefit from nature's contributions to people and diverse natural resources.
		Whenever relevant, note the relevance of genetic diversity for achieving other global and national targets: BSAPs can include crosswalks or connections of genetic diversity to other relevant biodiversity targets to identify synergies and make the best use of funds and resources for coordinated reporting (see text for example targets).
Implementation	Concrete actions, policies, and programs to meet the goals and targets	Describe actions that are expected to help maintain and restore genetic diversity, tailored to each country's capacity: BSAPs may describe and commit to actions that can help maintain and restore genetic diversity, such as supplementing populations, planning translocations, restoring habitat connectivity, and active management of threats.
		Outline specific policy mechanisms and programs that will facilitate positive action for genetic diversity. Complementing the commitment to action, it is helpful to describe the policies, legal frameworks, and programs that promote, fund, or facilitate such actions (e.g., national seed strategies, sustainable management, legal protection of subspecies and populations).
		Identify current capacity, capacity and financing gaps, and capacity building and long-term funding plans regarding genetic diversity: Describing current and needed capacity (e.g., regarding training, equipment, partnerships) can help facilitate the capacity-building support services that are currently being set under the GBF and foster collaboration among Parties and sectors. A long-term commitment and plan for funding will ensure consistency and secure knowledge and expertise over time.
Evaluation, review, support	Monitoring systems, reviewing and assessment	Describe monitoring, evaluation and review of genetic diversity, including choice of appropriate indicators, and available data. It is useful to describe indicators for reporting genetic diversity for both wild and domesticated species, and the country's capacity to report indicators, such as by listing monitoring programs and available data sets (using DNA or using non-DNA based proxies; Hoban et al. 2024a) that might be used to calculate genetic diversity indicators.
		Produce a plan for indicator calculation and reporting (agencies to be involved, data sources and data storage, and realistic timelines for gathering data): A plan for reporting, including which agencies are responsible, can help ensure that the identified actions, commitments, and reporting will have ownership. Identifying and using synergies with plans for other targets or programs can help make use of limited resources.
		Review the current state of knowledge, research and action on genetic diversity to inform audiences such as policymakers and the public: A synopsis of the current state of DNA-based assessments, or other knowledge on genetic diversity, and commitments or case studies of DNA-based knowledge or the use of DNA to guide management can be presented, in collaboration with in-country experts.

domesticated populations and breeds, although we focus more on wild populations because there are efforts already to sustainably use, conserve *in situ* and *ex situ*, and monitor the diversity of breeds and varieties important to agriculture, forestry, and aquaculture (e.g., FAO Commission on Genetic Resources for Food and Agriculture and the International Treaty on Plant Genetic Resources for Food and Agriculture). The main sections of the present article are structured to follow three areas of CBD's guidance to the Parties for NBSAPs (CBD/COP/DEC/15/6): setting national targets; developing actions, policies, and programs to meet the targets, and noting finance and capacity needs; and monitoring, review and assessment, including the use of indicators (table 1).

Previous papers cover related but distinct topics, such as introducing the genetic indicators (Hoban et al. 2020, Laikre et al. 2020), measuring genetic indicators in practice (Thurfjell et al. 2022, Mastretta-Yanes 2024), reviewing past CBD national reports (Hoban et al. 2021b), and reviewing the wording of the CBD GBF in the context of genetic diversity (Hoban et al. 2023a). No published papers have made an in-depth review of how genetic diversity can be applied in CBD NBSAPs, nor have any papers highlighted examples of genetic diversity in published NBSAPs.

Suggestions for setting national level targets

In this section, we provide four suggestions relating to setting national level targets, as per CBD notification.

Suggestion 1: Involve inclusive participation

Foremost, BSAPs will be more likely to succeed and will deliver wider societal benefits if their development involves inclusive participation and takes a rights-based approach, in line with section C of the GBF. As will be apparent from numerous examples in the present article, genetic diversity is a concern for managing ecosystems and species, as well as issues of human health, agriculture, livelihoods, and sustainability. Indonesia's BSAP (Government of Indonesia 2015) notes, "Erosion of sources of genetic diversity results in a serious threat to food security, shelter, and energy for the long term." Programs and agencies that are currently focused on species and ecosystem diversity can both use and contribute to knowledge on managing genetic diversity (e.g., genetic data can help guide restoration or protected areas, which you can see in suggestion 4, whereas knowledge from species monitoring can be used for genetic indicators, which you can see in suggestion 8). As with other levels of biodiversity, all relevant groups should be involved in efforts relating to genetic diversity, across a range of contexts (see also suggestion 4). Possible groups include, but are not limited to, academia, industry, indigenous peoples and local communities, natural resource and natural area managers, landowners, policymakers at local and national levels, business, civil society, conservation nongovernmental organizations, and youth (for examples, see figure 2). Inclusive involvement of all Parties can help ensure genetic diversity is conserved, as well as recognized and leveraged as a nature-based solution. It can be challenging to involve such a broad group in the creation and implementation of the BSAP, but participation can be facilitated through a range of mechanisms, such as virtual meetings and online public comments.

Suggestion 2: Set a national target on genetic diversity conservation within all species—native, wild, and domesticated—that is aligned with (containing the same components and ambition as) the global target

Genetic diversity is one of three components of biodiversity in Article 2 of the convention's text ("Biological diversity… includes diversity within species, between species and of ecosystems" UN 1992). A national target specifically on genetic diversity of all species, including both wild and domesticated (terrestrial and aquatic), can help address adaptive potential, population size, inbreeding, and other processes that ultimately help to conserve genetic diversity within and between populations, as well as species and ecosystem diversity, as is the intent of the GBF's Target 4 (figure 1). Adopting a formulation of the global target for national purposes will ensure this essential component of biodiversity is not neglected. As was noted in Japan's BSAP (Government of Japan 2023), "A decline in genetic diversity will threaten the persistence of species… Genetic diversity may be declining not only in rare species with small populations, but also in species with fragmented habitats and shrinking population sizes." Consequently, a possible target could try to ensure genetic diversity is maintained within populations, that all populations are maintained and that genetic connectivity is maintained and restored between populations, thereby enabling natural adaptive and evolutionary processes within species. Papua New Guinea's BSAP (Government of Papua New Guinea 2019) emphasizes the importance of maintaining evolutionary processes. Meeting such a national target on genetic diversity can be accomplished through associated activities (see suggestions 8–10).

We see room for improvement in some national genetic diversity targets—for example, from Sweden and China: "The adaptability of species is strengthened by preserving and enhancing genetic diversity" (SEPA 2024) and "maintain and restore genetic diversity of local, wild and domesticated species" (Government of China 2024). We suggest these examples could be better aligned with the global target (GBF Target 4) by specifically committing to maintain, restore, conserve *in situ* and *ex situ*, and sustainably manage within and between population genetic diversity (see figure 1). These specific components of the GBF are noted in several BSAPs, such as in Serbia's (Government of Serbia 2021), where "populations require particular attention from the aspect of conservation, since they contribute significantly to the total genetic diversity of these species." Argentina's BSAP (Government of Argentina 2017) states a need for "the conservation of genetic variability, which is crucial for the demographic viability of subpopulations, and their connectivity and distribution throughout Argentina's ecoregions and subregions." Furthermore, the Republic of Ireland's BSAP notes that "Genetic diversity is important because it gives a better chance of survival in the face of environmental change. The breakup and loss of habitats can reduce genetic diversity by creating smaller, inbreeding populations. These populations then struggle to adapt to environmental changes such as drought" (Government of Ireland 2024).

For countries that use regional or subregional coordination to meet shared goals and targets, national targets may be designed or presented in light of regional targets or on the basis of regionally negotiated frameworks. For example, the SADC (SADC 2024) has a target to "Develop and execute comprehensive conservation strategies by 2035 to effectively mitigate the genetic erosion of biological resources, emphasizing the sustainable management of plant and animal genetic diversity, promotion of resilient agricultural practices, and establishment of seed banks or genetic repositories." Meanwhile, the Pacific Islands Framework for Nature Conservation and Protected Areas 2021–2025 (SPREP 2021) has an objective to "Protect and recover threatened species and preserve genetic diversity" and states that "Connections among protected areas are essential for their survival, to maintain genetic diversity and 'restock' populations after a disaster, such as a bleaching or disease event." Individual countries can adopt such targets and go beyond by specifying targets or subtargets, local context, higher ambition, or how they can be applied to wild and domesticated species.

Suggestion 3: If possible, set national targets that are more ambitious and specific, including means of achievement

Higher ambition in genetic diversity conservation and management can help countries benefit from nature's contributions to people and diverse natural resources. An analysis of the wording of GBF Target 4 (Hoban et al. 2020, 2023a) recommended that a target include policies and strategies (in addition to management actions), such as "Develop and initiate national-level policies and strategies, and take urgent management action, to maintain and restore the genetic diversity within and between populations of native, wild and domesticated species to maintain their adaptive potential, including through *in situ* and *ex situ* conservation and sustainable management practices, and develop and initiate national-level strategies and resources for conserving genetic diversity." Policies could focus on legal protection (e.g., of local breeds or of distinct populations) or strategic investment of resources (e.g., funding genetic monitoring programs, habitat

Figure 2. Examples of effective inclusive partnerships. (a) Conservation planning workshop for the helmeted hornbill (*Rhinoplax vigil*) in Malaysia in 2017. The participants represented 28 organizations from government, nongovernment organizations, academia, field experts, donors, and a zoological

Figure 2. *(Continued)* institution. (b) Two workshops held in Mexico in 2021 for the arroyo oak (*Quercus brandegeei*), one with communities (local ranchers and landowners), scientists, and government leaders to share knowledge about species occurrences, ecosystem, and the community needs, and to build connections for larger community interest in the species and the other with local nongovernmental organizations, local and provincial government, and scientists to share research updates and collaboratively plan a comprehensive species action plan. (c) Greater bilby (*Macrotis lago*) in Recovery Summit, in Australia in 2015. Thirty-nine participants from 29 organizations representing state and federal governments, universities, geneticists, zoos, community groups, conservation, and nongovernmental organizations.

restoration or *ex situ* collections, management, or gene banks). Genetic conservation strategies and planning can define priority species for genetic monitoring, incorporate genetic diversity into spatial planning (including landscape connectivity), set timelines for capacity building, and prepare comprehensive reports on progress toward conserving genetic diversity (Posledovich et al. 2021). Of course, the Parties may find other ways to make their national targets more ambitious or specific, such as providing emphasis on genetic connectivity or including expected outcomes. The Parties may wish to specify which aspects of their national targets on genetic diversity can be achieved with existing resources and where more resources are needed.

Suggestion 4: When possible, note the relevance of genetic diversity for achieving other global and national targets

By identifying links to genetic diversity throughout their BSAPs, Parties can underline the coherence of policies across sectors, and optimize monitoring programs. Genetic diversity monitoring and indicators can serve multiple reporting needs and therefore alleviate the reporting burden on Parties (a recurrent issue). Genetic diversity is vital for meeting various targets, including Targets 2, 3, 4, 6, 8, 9, 10, 11, and 13 (Hoban et al. 2020, 2021b, 2023a, Bolam et al. 2023). These targets relate to topics such as restoring degraded ecosystems, conserving and managing terrestrial and aquatic areas, management actions for recovering species and conserving genetic diversity, addressing the impacts of invasive species, minimizing the impacts of climate change on biodiversity, sustainable management and use of wild species, enhancing sustainability in fisheries, forestry and agriculture, restoring and sustaining ecosystem services, and increasing the sharing of benefits from genetic resources and traditional knowledge (these are simplified and not meant to embody the full targets' intent; the full text of targets can be found at www.cbd.int/gbf/targets). Highlighting such interconnections can strengthen commitments to biodiversity at all levels.

For example, when relating to a possible Swedish national target on restoration, SEPA (2024) states, "In… implementation of the framework, it is important to take into account ecological representativeness and connectivity that contribute to genetic exchange between populations." and Serbia's NBSAP (Government of Serbia 2021) intends to "integrate ecological corridors, as part of identified Trans-European Nature Network to prevent genetic isolation, allow for species migration, and maintain and enhance vitality of ecosystems." Indonesia's BSAP (Government of Indonesia 2015) notes that protected areas serve to conserve both species and genetic diversity. Regarding genetic diversity and invasive species and sustainable agriculture and fisheries, Sweden (SEPA 2024) aims for the "introduction of alien genotypes that are potentially harmful to biodiversity [to be] strongly limited until 2030" and states that "sustainable fishing practices will include maintenance of genetic diversity and avoidance of strong selective harvest that alters species' genetic diversity," whereas Colombia's BSAP (Government of Colombia 2017) notes that at least 57 nonnative marine species threaten to reduce genetic diversity.

Suggestions for developing concrete actions, policies and programs to meet the goal and targets, and noting finance and capacity needs

In this section, we provide three suggestions relating to developing actions, policies and programs to help meet the goal and targets, as per CBD notification.

Suggestion 5: Describe actions that are expected to help maintain and restore genetic diversity, tailored to each country's capacity

Tangible actions to support genetic diversity include restoring lost habitat connectivity to facilitate gene flow, preventing the loss of distinct populations, documenting and preserving local breeds and varieties, and enabling population growth for small populations (e.g., halting poaching, removing invasive predators) to maintain evolutionary potential (Fady et al. 2016, Hohenlohe et al. 2021, Willi et al. 2022). If populations cannot achieve sufficient size on their own, intensive management can include *ex situ* breeding and release or translocation of individuals (Bolam et al. 2023). Actions should both be *in situ* and *ex situ* and include laws, funding, and management (Hoban et al. 2021b).

Example commitments include to "promote augmentation programs by releasing individuals into existing populations to increase their size and genetic diversity" (Government of Cambodia 2016), to "rescue populations with risks of genetic loss or erosion" (Government of Uruguay 2016), "special efforts to increase the effective population size of populations of native wildlife species with an effective population size below 500 have commenced by 2025" (SEPA 2024), and that "all native wild species subpopulations or geographic distribution [be] maintained or reestablished to strengthen genetic diversity, if ecological and technical conditions exist" (SEPA 2024).

As a specific example, in marine conservation, cooperation between Indonesia and 14 other countries aims to increase local population sizes of depleted shark populations (www.reshark.org), which can benefit genetic diversity maintenance. Of course, augmentation and release should follow best practices, including weighing beneficial and adverse outcomes of translocations, and should consider the balance of local adaptation and genetic erosion (Weeks et al. 2011, IUCN/SSC 2013). As was explained in Japan's NBSAP (Government of Japan 2023), "Since there is a high possibility of genetic differentiation between native species naturally distributed in Japan and the same species distributed outside of Japan, there is concern that the introduction or artificial release… may cause hybridization." Meanwhile, the Brazilian National Fund for Benefit Sharing helps to conserve genetic heritage *ex situ* (Government of Brazil 2018). Numerous countries commit to the important task of identifying and conserving genetic resources, such as local breeds and varieties, and to building or enhancing gene banks or biobanks. *Genetic diversity* and *genetic resources* have different meanings and should not be used interchangeably (box 1); however, we acknowledge this may not be evident to all given the predominant use of *genetic resources* in all BSAPs reviewed in this study (table 2).

Table 2. Frequency of use of various genetic terms in the 21 national and regional biodiversity strategy and action plans reviewed for this manuscript.

	Number of times each term is used*			
Country or region	**Genetic**	**Genetic diversity**	**Genetic erosion**	**Genetic resources**
Argentina	99	8	1	54
Australia	3	2	1	1
Barbados	60	25	7	15
Brazil	106	3	0	3
Cambodia	157	39	2	93
China	74	7	0	61
Colombia	3	1	0	2
France	18	4	0	4
Indonesia	145	15	1	47
Republic of Ireland	29	8	0	11
Japan	101	20	0	54
Papua New Guinea	32	7	0	16
Republic of Korea	119	23	0	75
Serbia	106	25	2	60
Spain	13	1	0	11
Sweden	60	12	0	34
Tunisia	16	1	1	11
Uruguay	8	4	2	27
European Union	3	1	0	1
Southern African Development Community	172	23	12	112

Note: The reports vary widely in length, and the numbers should not be compared directly between countries. For NBSAPs not written in English, the counts represent language-specific translations of these terms.

Box 1. The differences between genetic diversity and genetic resources

Equitable sharing of the benefits of genetic resources is one of the objectives of the Convention, along with biodiversity conservation and sustainable use. It is important to note that *genetic resources* and *genetic diversity* are not synonymous and that achieving targets on genetic resources and genetic diversity will each need specific attention, policies, actions, and reporting.

Genetic diversity is the amount of variation within species and their populations (or breeds), which can be observed in trait variation (e.g., thermal tolerance, color, size, shape, phenology, mating calls) and which is based on DNA variation. Genetic diversity helps species adapt and avoid inbreeding depression. Maintaining genetic diversity means preventing the loss of genetic diversity and supporting conditions for adaptive change. Assessing and reporting on the genetic diversity of populations or breeds within species can include reporting effective population sizes, the loss of populations, levels of neutral and adaptive diversity, levels of genetic structure, and of the impacts of processes such as hybridization and inbreeding (for both wild and domesticated species). It is not necessary to have DNA sequence data for this reporting, but such data does inform conservation and management action for genetic diversity. Sequence data can be summarized in forms that do not require publishing sensitive information (Hoban et al. 2024a).

Genetic resources are "genetic material of actual or potential value.... *Genetic material* means any material of plant, animal, microbial or other origin containing functional units of heredity" (CBD, Article 2). The term is frequently used in BSAPs and national reports in reference to domesticated species or their wild relatives—especially regarding breeds, landraces, and similar units—but it could apply to any species. Many BSAPs have commitments on genetic resources, such as conserving traditional varieties on farms and managing, cataloging, increasing and using samples in gene banks. Some BSAPs and national reports also report the numbers of species in a country with possible use in medicine or food, or numbers of wild relative species, when reporting on the status of genetic resources. We note that a metric of the number of species, while a summary of genetic resources, is not a measure of genetic diversity within species.

Suggestion 6: Outline specific policy mechanisms and programs that will facilitate positive action for genetic diversity

We distinguish policies and programs (as opposed to actions) as being at a higher level than on the ground actions, such as designation of protected status for distinct populations or breeds and their evolutionary adaptations (as in several national endangered species laws), or increased funding in the form of grants for local and regional authorities in charge of wildlife and habitat management. Although China (Government of China 2024) commits to the "conservation and recovery of rare and endangered species and very small populations [and to preventing] changes in genetic diversity," and Barbados (Government of Barbados 2021) states that marine protected area planning (e.g., spatial planning) should "ensure their long-term viability and to maintain biological and genetic biodiversity", BSAPs would ideally describe specific agency policies, programs, or funding mechanisms. The United States (not a Party to the CBD) proposed a law (Recovering America's Wildlife Act, bill S.1149) that would provide funding to fully implement management plans to help threatened species. The authority for implementation would be state wildlife and forest management agencies. Another example is the Republic of Ireland's BSAP (Government of Ireland 2024), which aims to increase opportunities under agriculture, rural development, forestry, and other relevant policies to benefit biodiversity by 2027. The plan commits the National Parks and Wildlife Service and the Department of Agriculture, Food, and the Marine to implementation, including by supporting "farming for nature initiatives that specifically enhance ecological connectivity." Meanwhile, China's State Forestry Administration and the National Development and Reform Commission have initiated a program to restore plant species with extremely small populations (Yang et al. 2020), and Uruguay (Government of Uruguay 2016) aims to "promote scientific production and valuation of genetic resources." Papua New Guinea's BSAP (Government of Papua New Guinea 2019) suggests that forestry and fisheries policies could have a greater "emphasis on genetic and biodiversity conservation."

As another example, Parties may wish to establish a genetic conservation unit (GCU) program (Minter et al. 2021). GCUs are designated land or aquatic areas that maintain viable and evolving populations *in situ*, to support future adaptation. Designating and tracking GCUs involves identifying populations or portions of populations that are of sufficient size and contain important or unique genetic diversity. A database of GCUs can help to ensure sufficient genetic diversity is maintained, focus monitoring efforts, and allow quick identification of source material for restoration. The European Forest Genetics program tracks nearly 4000 GCUs across Europe for more than 100 species in 35 countries (Lefèvre et al. 2020). GCUs can help to serve the needs of commercial forest management or other species harvest. GCUs are not limited to forest trees and could be applied to many plants and animals and possibly fungi (Minter et al. 2021). Existing protected and managed areas may already function as GCUs for some species groups, highlighting mutual achievement of Targets 3 and 4.

Another option is to create national native plant or seed strategies or indicate participation in the subregional or regional equivalent (e.g., the Pacific Community's Centre for Pacific Crop and the Trees gene bank). Such strategies help to ensure that restoration of habitat will include genetically diverse and genetically appropriate plant material (Gaisberger et al. 2023). Ideally, such strategies and actions will address both wild and domesticated species. Because producing such material relies on a chain of infrastructure and logistics, a national strategy must be focused on the full cycle of restoration needs (planning seed collection, sufficient farms to grow native seed, facilities for storing seed, nurseries, education, expertise to inform planting in the right place with the right care; Basey et al. 2015, Di Sacco et al. 2021). The French BSAP (Government of France 2023) notes that the Végétal Local brand helps ensure preservation of genetic diversity by guaranteeing wild origin and not using artificial selection, whereas maintaining forest genetic diversity supports resilience. Serbia's BSAP (Government of Serbia 2021) notes that the Trans European Nature Network (Fornarini et al. 2024), a set of ecological corridors, could help facilitate gene dispersal; the IUCN's guidelines on connectivity also mention that an ecological network should quantify the impact on genetic diversity (Hilty et al. 2020). In Spain, royal decree no. 159/2022 (Government of Spain 2022) established the National Bank of Forest Germplasm and Wild Flora "to effectively conserve the material of forest species,… ensuring their availability and addressing the conservation and reintroduction needs."

Other plans might include promoting the use of locally sourced native plant species in restoration projects and implementing habitat restoration that prioritizes the conservation of genetic diversity (Hilty et al. 2020). In Japan, there are "Technical Guidelines for Reducing the Risk of Impacts on Genetic Diversity Related to the Release of artificially bred Juvenile Fish" (Fishery Research Agency 2015). Forestry, fisheries, agriculture, and wildlife management agencies could be named as being responsible for creating such guidance. Meanwhile, genetic diversity of crop wild relatives can help innovative, sustainable agriculture. In Argentina, transitioning to multifunctional landscapes within large-scale farming systems holds significant potential for enhancing biodiversity and promoting landscape connectivity (Garibaldi et al. 2023). In Brazil, among the 10 countries with the highest numbers of plant genetic resources stored in long-term facilities, a national plan for keeping plant genetic resources was established with a physical structure to house 700,000 accesses (Ministry of the Environment 2023), whereas Tunisia (Government of Tunisia 2019) aims to develop a "system for the protection of traditional knowledge related to genetic resources" and to "update and implement the conservation and valorization strategy of local agricultural genetic resources."

Suggestion 7: Identify current capacity, capacity and financing gaps, and capacity building plans regarding genetic diversity

Capacity may include resources within the country to monitor and report on genetic diversity, to implement actions that support genetic diversity, or general training or expertise, which will vary among Parties (see box 2). For example, ecological restoration has sometimes neglected genetic diversity concerns, resulting in the establishment of restoration sites with low genetic diversity, decreasing adaptive potential of populations, high inbreeding, and diminished survival and productivity. Updating management practices to include genetic diversity will require training and collaboration between geneticists and practitioners and possibly others (e.g., see Frankham et al. 2019). Calculating genetic indicators for wild populations, which are fairly new, may also require training. Overall, such capacity building should include cross-sectoral cooperation on genetic diversity conservation, which will enhance the knowledge, skills, resources, and institutional capacities of different sectors (e.g., across agencies and levels of government and across research, practice, and industry). Adopting engagement strategies across varied sectors can also reach broader audiences and lead to constructive dialogue on genetic diversity across different interests and perspectives. We emphasize that identifying barriers to implementation should not preclude inclusion of genetic diversity in BSAPs. Indeed, recognizing barriers can inform where capacity building is needed and facilitate links among Parties and with organizations providing support.

Box 2. Challenges and opportunities for some countries on including genetic diversity in BSAPs

All BSAPs reviewed mention genetic diversity in some form, albeit to various extents (see supplemental document S1 and supplemental tables S1 and S2). For the majority of Parties yet to submit updated BSAPs, ambitious and clear targets and actions restoring and maintaining genetic diversity within wild and domesticated species should be feasible.

Still, we acknowledge challenges faced by countries with limited financial and technical resources. Management actions, enforcement of legislation, and monitoring of genetic diversity all require funds, personnel, and expertise. The GBF does commit to additional resourcing and capacity building but gaps remain. Technical capacity around genetic diversity may be lower in developing economies, which means that training, exchange visits, workshops, and published guidance are needed.

Monitoring and management needs are also higher in countries with higher numbers of species; more species need to be evaluated and more species will need active management interventions to improve their genetic diversity status (Ragamustari and Sukara 2019). But generally, the highest diversity falls within developing economies, where less resources are often available. Even the substantial budget allocation by SADC (more than US$20 million) to address genetic diversity and genetic resources over 10 years across SADC countries, is less than US$140,000 per year per country (SADC 2024).

Large nations with numerous isolated or remote areas face challenges in the logistics of monitoring and in determining whether populations are isolated. For example, the sheer area and high biodiversity in countries such as Brazil and Indonesia pose challenges for monitoring populations, assessing their census sizes, or collecting samples for genetic analysis. Countries with populations of highly mobile marine species also face difficulties identifying populations. Transboundary cooperation will be essential for assessing and monitoring genetic diversity of these populations. Marine organisms, invertebrates, fossorial organisms and other species that are hard to count may be challenging, although using a combination of emerging technologies, Red List experts and workshops, citizen science, and Earth observation data will be helpful in tackling these challenges.

Meanwhile there are opportunities to leverage community participation. In addition to establishing community seed banks to help preserve genetic lines, indigenous peoples (IPs) and local communities (LCs) often have knowledge on genetic diversity in the form of unique traits, behavior, or other within-species variation. IPs and LCs can sometimes contribute knowledge on the number of individuals within a species (and decrease in numbers or area occupied) or loss of a species from a local area, contributing to monitoring and reporting. The existing knowledge and the participation of IPs and LCs could help alleviate some of the monitoring challenges noted above (large numbers of species, limited financial and technical resources, large numbers of islands), whereas in all countries complementing other forms of knowing and monitoring biodiversity. Other stakeholders can also help. For example, local volunteers, farmers and foresters were able to design a successful conservation management plan for a European Protected Species of amphibian, the great crested newt (*Triturus cristatus*), that combined genetic evidence with local stakeholder knowledge (O'Brien et al. 2021). Involving diverse stakeholders is therefore important for successful conservation planning (see also the IUCN SSC Conservation Planning Specialist Group, www.cpsg.org)

Training programs tailored to practitioners and decision-makers are essential for raising awareness about the significance of genetic diversity and for building knowledge of relevant national and international regulations. Educational initiatives play a crucial role in providing the knowledge, skills, and confidence needed to make informed decisions about conserving genetic diversity. In addition, training programs in genetic diversity can empower decision-makers to initiate actions, effectively allocate resources, and advocate for impactful conservation measures. By fostering a culture of innovation, collaboration, and inclusivity, these educational efforts cultivate a new generation of leaders capable of driving positive change in biodiversity conservation. For example, in Argentina, the educational modules established under the Yolanda law (law no. 27,592, passed in November 2020) require environmental training for all public service employees—a crucial starting point for enhancing capacity, awareness, and collaboration to fulfill the nation's biodiversity commitments. Argentina's BSAP (Government of Argentina 2017) also emphasizes training for companies regarding understanding of genetic resources. Similarly, the SADC (SADC 2024) commits to developing and implementing "programs for member states to empower local communities to actively participate in monitoring and addressing genetic erosion in their region." In addition, in Brazil, public service employees responsible for proposing, implementing, and managing nationwide conservation policies are being trained on DNA-based methods for monitoring and conserving genetic biodiversity and participating in the Genomics of the Brazilian Biodiversity consortium (Vilaça et al. 2024). Similarly, in its fifth national report, Algeria commits to revise university training and education to better meet the needs of biodiversity management, specifically noting new techniques in genetic diversity conservation (People's Democratic Republic of Algeria 2014).

Such training can build on and coordinate with a wealth of prior capacity around genetic resources for food and agriculture. National focal points for plant, animal, forest, and aquatic genetic resources within countries have experience monitoring, preparing country reports, coordinating implementation, and more. They are often supported by dedicated experts and practitioners. In addition, the Domestic Animal Diversity Information System (www.fao.org/dad-is/en) already monitors the population sizes of domesticated animal breeds, and their expertise in gathering, storing, and presenting data would be valuable for reporting on indicators for genetic diversity of wild populations. Numerous guidance and tools are available at the FAO Biodiversity Knowledge Hub (www.fao.org/biodiversity/knowledge-hub/en).

Suggestions for monitoring systems, reviewing and assessment, including the use of indicators

In this section, we provide three suggestions relating to monitoring, reviewing and reporting, as per CBD notification.

Suggestion 8: Describe the monitoring, evaluation, and review of genetic diversity, including the choice of appropriate indicators and, if possible, a list of local, national, and regional monitoring programs and available data sets that might be used to calculate genetic diversity indicators

Several indicators of genetic diversity are contained in the GBF (CBD 2022). The headline indicator on proportion of populations (or breeds) with an effective size greater than 500 and the complementary indicator on the proportion of populations maintained allow for the quantitative assessment of genetic diversity status within and among populations, respectively (Hoban et al. 2020, Mastretta-Yanes et al. 2024). Their main advantages include feasibility, affordability, speed, and relatively straightforward interpretation of indicator values and their change over time, making them suitable for inclusion in Parties' plans for monitoring, evaluation, and review, especially considering that Parties are obligated to report on the headline indicator. Australia's BSAP (Government of Australia 2021) alludes to both of these indicators with the text "Species will need to maintain large, genetically diverse populations to adapt.… This fundamental requirement is challenged by other pressures reducing population size (e.g., invasive species, habitat loss) or connectivity of suitable habitat (habitat fragmentation)," and in-progress measures of the "number of populations of threatened or near threatened species… in government managed reserves [and]… protected by private landowners through stewardship or other arrangements." These indicators are ready for use, leverage diverse data, and are inclusive and fairly rapid (Hoban et al. 2024a).

Another indicator, the genetic scorecard (Hollingsworth et al. 2020) provides an assessment of genetic status, synthesizing various genetic processes and actions for genetic conservation in a way that is accessible to help land managers, policymakers, and others effectively steward and allocate resources at a local, landscape, or national scale. An indicator for monitoring genetic diversity of crop wild relatives uses geographic proxies to identify the protection level of *in situ* and *ex situ* populations (Khoury et al. 2019). Regarding domesticated species, indicators exist to track the proportion of local breeds that are threatened and the number and diversity of accessions in medium to long-term storage facilities (CBD/COP/15/5). All of these can be compiled without any DNA-based data, using existing data and knowledge.

To facilitate planning for reporting indicators, it will be valuable to make a list of local, national, and regional monitoring programs and available data sets that could contain the data needed to calculate genetic diversity indicators. The indicators for monitoring genetic diversity currently in the GBF do not require DNA-based data and can therefore leverage conventional monitoring such as counts of individuals or spatial surveys of populations as well as qualitative knowledge (Hoban et al. 2023b, 2024a). The BSAP could present a list of relevant programs and sources of information on counts of populations and occurrences over time (or links to existing data sets and databases). This may include existing national, state, or regional population surveys or inventories, volunteer or citizen science-based programs, community-based monitoring, and monitoring habitat area using remote sensing. National examples include the United Kingdom's National Forest Inventory and the Republic of Korea's National Ecosystem Survey. These two programs are systematic national-level surveys across many species, but many other species are monitored by state or other authorities and small nongovernmental organizations. Other national and transnational examples include programs to monitor large mammals such as moose, caribou, bears, lions and jaguars. Globally, the FAO Commission on Genetic Resources for Food and Agriculture monitors the state of the world's genetic resources for food and agriculture.

Suggestion 9: Producing a plan for indicator calculation and reporting, including what agencies will be involved, what the data sources and data storage mechanisms will be, and what are realistic timelines for gathering data

This is vital to ensure that personnel and resources are allocated, that logistics are in place and that there is accountability and a chain of reporting. In the Republic of Ireland's report (Government of Ireland 2024), genetic diversity is partly assigned to the National Parks and Wildlife Service and the Department of Agriculture, Food, and the Marine. In the Republic of Korea's report (Republic of Korea 2019), several agencies are named as responsible for reporting on genetic diversity, including the Ministry of Science and ICT (for *information and communication technology*), the Ministry of Health and Welfare, the Ministry of Environment, the Ministry of Oceans and Fisheries, the Rural Development Administration and the Korea Forest Service, reflecting the GBF's aim to mainstream biodiversity across society. Of course, having too many agencies involved could have downsides (e.g., fragmented responsibilities and implementation), and clear responsibilities for each agency would be beneficial. When numerous agencies are involved, efforts are needed to ensure interoperability of data and information collected and archived. Parties needing help reporting genetic diversity indicators can find help from in-country biodiversity researchers, as well as from bodies that are being set up to support GBF implementation (CBD/COP/DEC/15/8; see also supplemental document S2).

As is noted in box 2, nongovernmental organizations, farmer or landowner groups, and indigenous peoples and local communities are important partners in indicator reporting. Brazil's BSAP (Ministry of the Environment 2023) commits to "conserve the genetic diversity of local traditional or crioula varieties locally adapted by indigenous peoples, traditional communities, and family rural producers." Collaboration can also be employed across different targets to promote synergy with GBF reporting and facilitate methodological coordination and data and knowledge sharing. A genetic diversity indicator pilot in Colombia materialized this in two ways, which optimized biodiversity assessment. First, workflows and outcomes from different initiatives that could provide information relevant to genetic diversity indicators were coordinated, such as Red List assessments, protected areas management plans, systematic data collection, and systematic expert consultation initiatives (Velásquez-Tibatá et al. 2019). Estimation of the indicators provided data on the genetic diversity status of evaluated species, as input for their management and conservation, and could lead to the prioritization of populations for monitoring using DNA data (Hoban et al. 2023b). Genetic diversity indicators are being implemented in other initiatives such as the Multidimensional Biodiversity Index (Soto-Navarro et al. 2021). Second, through the Key Biodiversity Areas initiative, which identifies sites that contribute significantly to the global persistence of biodiversity on the basis of the representation of species' populations (e.g., abundance, conservation status, distinctness), workshops were held to assess historical and current species distribution data—necessary for both key biodiversity areas and genetic indicators. Genetic assessments also helped define population boundaries and determine the distinctiveness of an area. This collaborative effort illustrates how genetic diversity indicators can strengthen other biodiversity monitoring systems.

Suggestion 10: Review relevant existing national, regional, and global reports and summarize the current state of knowledge, monitoring, and action on genetic diversity to inform audiences such as policymakers and the public

Reviewing what is known about genetic diversity in wild and domesticated species in country can be a valuable comparison for the aforementioned plans. If the in-country knowledge and capacity is insufficient, this should be noted as a capacity need. Scotland produced a report on 26 nationally important species using simple proxies that are understandable by the public and policymakers (Hollingsworth et al. 2020). Recently, Pearman and colleagues (2024) counted the number of multiyear DNA monitoring programs in 38 European countries. Additional reports can be focused on particular sectors or groups such as forestry, fisheries, crop wild relatives, or game species, or particularly threatened species. Existing global and national reports on genetic diversity in forests or in food and agriculture provide useful models (FAO 2007, 2010, Black-Samuelsson et al. 2020). Reporting could assess the current capacity for DNA-based monitoring (e.g., reporting the number of government and academic labs with genetic equipment, number of university training programs in conservation genetics) and could count the number of species that have had DNA-based studies performed or species in which DNA-based methods are supporting management and recovery. A Swedish model of such a report, codrafted by researchers and the Swedish Environmental Protection Agency, counted the number of species being genetically monitored and summarized current genetic technology and capacity (Posledovich et al. 2021). Several BSAPs note that systematic and ongoing analysis of genetic diversity at a landscape scale will facilitate the achievement of the targets proposed (of numerous countries, including Spain, the Republic of Korea, and the Republic of Ireland), including those related to enhancing ecological connectivity. Countries can also commit to reviewing relevant policies, plans and reports, such as to “review plans and strategies that are in place to maintain the plant and animal genetic diversity for food and agriculture and genetic diversity of other planted species *in situ* and *ex situ*” (Government of Cambodia 2016). In addition, documenting and evaluating the success of past policies and actions is critical to informing future practices and policies.

As was previously noted, case studies are an effective way to translate genetic issues and knowledge to nongeneticists. We recommend BSAPs summarize the findings of selected DNA-based studies of species of interest and explain any DNA-based management actions. The use of genetic sequencing is not necessarily limited to developed countries. The BSAP of Cambodia (Government of Cambodia 2016) describes the use of DNA-based studies to distinguish hybrid from nonhybrid individuals of Siamese crocodile (*Crocodylus siamensis*), and the use of noninvasively collected (from feces) DNA samples to estimate the population size of elephants (*Elephas maximus*) in the country. It also mentions the “development and strengthening of capacity for using DNA-based methods for species identification and genetic diversity studies, and for parentage, population structure and ecosystem health studies.” Serbia (Government of Serbia 2021) notes that projects have examined “genetic differentiation of populations… for some wild species… the horned viper (*Vipera ammodytes*) or green frogs (*Rana synklepton esculenta*), or of game/mammals, such as the roe deer (*Capreolus capreolus*)… brown trout (*Salmo trutta*), grayling (*Thymallus thymallus*).” Genetic data can also be used to study invasive species, as was mentioned in the Barbados BSAP, regarding the introduced hare (*Lepus europaeus*) (Government of Barbados 2021). Parties could collaborate with genetic scientists to summarize results of high interest and to motivate further applications of conservation genetics in practice.

For those countries with sufficient capacity to do so, commit to increasing DNA-based genetic monitoring

Some countries will be able to make concrete commitments to expand on existing monitoring of genetic diversity, including DNA-based monitoring. This could involve sampling tissues (or excretion) of organisms and analysis of its DNA, which can result in metrics regarding levels of population heterozygosity, numbers of migrants between populations, local adaptation, hybridization and other facets (including DNA-based estimates of current and historic effective population size). This can be useful for informing management or protection decisions (Hoban et al. 2024b). The Swedish draft report (SEPA 2024) proposes that “The number of native wildlife species and populations that have been analyzed with genetic diversity has increased significantly and the monitoring of genetic diversity is carried out on an ongoing basis.,” whereas China commits to “explore surveys of the genetic diversity of wild organisms.” A number of examples are included in the Republic of Korea’s BSAP (Republic of Korea 2019): “Carry out trial research to identify and monitor on a regular basis the genetic diversity of endangered species, endemic species and species with high economic value. Use the results… for management, listing/delisting of endangered species and selection of species to be introduced for recovery.” The Republic of Korea commits to specific goals: “202 cases analyzed as of 2018. 356 species will be analyzed from 2019 and 2026 (32 cases/year)” and to “evaluate regional adaptation characteristics through the development of high-density DNA markers… 5 species of tree, 90 markers (2017) → 15 species of tree, 450 markers (2022).” Another specific example is given under the Republic of Korea’s target on sustainable agriculture, forestry, and fisheries, as to monitor genetic diversity: “Cultivate sea forests (3000 [hectares] per year) to recover coastal ecosystems… and monitor their genetic diversity.” Several countries commit to better documentation of local or regional landraces, breeds, or varieties using DNA-based and non-DNA based proxies.

Conclusions

We hope that this guidance provides Parties and other entities with a starting point; a checklist of possible considerations, and encouragement for including ambitious and specific targets, actions, policies, and monitoring for genetic diversity in their BSAPs. Parties may ask which of these suggestions are most important. We connected our suggestions to the requirements of NBSAPs according to the GBF (table 1) and with the possible exception of suggestions 3 and 10, we anticipate that the guidance provided is all equally important, being fundamental to completing obligations to the CBD. For further inspiration, a more complete list of quotes from the examined BSAPs can be found in supplementary document S1, and a short list of online resources for integrating genetic diversity into policy and practice can be found in supplemental document S2. To envision putting a plan into place, a high-level picture is shown in table 1, mapping the 10 suggestions to the policy cycle. We close by noting that it is of course important to connect the BSAP to national reporting and implementation on the ground, so that commitments are not left behind (Maney et al. 2024).

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Supplemental data

Supplemental data are available at *BIOSCI* online.

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