Conservation Genetics (2021) 22:533–536
https://doi.org/10.1007/s10592-021-01359-w

LETTER TO THE EDITOR

Authors' Reply to Letter to the Editor: Continued improvement to genetic diversity indicator for CBD

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Accepted: 24 March 2021 / Published online: 22 April 2021

We appreciate the encouraging response to our call for indicators for genetic diversity within the post-2020 Global Biodiversity Framework of the Convention on Biological Diversity, CBD (Laikre et al. 2020; Hoban et al. 2020). In agreement with us, Frankham (2021) highlights the urgent necessity for the CBD to include an indicator that tracks the maintenance of genetic diversity within populations of all species—wild and domestic. Draft CBD Headline indicators (which all CBD Parties will need to report) do not include genetic diversity *within populations* of wild species (CBD/SBSTTA/24/3Add.1).

The genetically effective population size (N_e) is a metric that quantifies the rate of genetic change within a population. We welcome Frankham's (2021) comments on the relevance of this important parameter, and the appropriate indicator threshold ($N_e > 500$ or $N_c > 5000$; N_c = adult census size, the

This reply refers to the comment available online at https://doi.org/10.1007/s10592-021-01357-y.

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number of sexually mature individuals). Frankham (2021) suggests rewording our proposed indicator 1, "*The number of populations [or breeds] within species with an effective population size > 500 compared to the number < 500",* to *"The number of populations (or breeds) with > 5000 mature individuals compared to the number < 5000."* The proposed rephrasing coincides with our suggestion that in the absence of empirical knowledge on N_e, the relationship $N_e/N_c \approx 0.1$ can be assumed, substituting $N_c \approx 5000$ for $N_e \approx 500$ (Fig. 1). We included published estimates of N_e from many populations (Hoban et al. 2020, 2021), recognizing they were not always directly comparable depending on methods used; we appreciate Frankham's examination of subsets of estimates, which also supports a ratio of approximately 0.1 for many species.

Frankham (2021) proposes that his wording is simpler and more suitable for a policy audience. We agree that N_e may be conceptually challenging, but we remain convinced that, even if $N_c > 5000$ will often be used as a proxy, the term "genetically effective population size" has important meaning in policy (including the CBD, the EU Biodiversity Strategy, and others) for several reasons:

(1) N_e stresses that within-population genetic diversity is the indicator's focus. We consider it critical to signal to policy makers that census size N_c is not a sufficient metric to track how fast a population loses genetic diversity. The recent CBD document CBD/SBSTTA/24/3Add.2 acknowledges this: "While population abundance is a key factor in the maintenance of genetic diversity, it is not a sufficient indicator since it does not account for within-population genetic diversity".

(2) Including N_e could spur CBD Parties to initiate more genetic monitoring efforts that will increase availability of robust estimates of N_e or taxon-specific N_e/N_c ratios. Also, N_e estimates should rapidly increase with the broadening availability of genomic and bioinformatics resources and large-scale databases (Santiago et al. 2020; Lawrence et al. 2019).

(3) The CBD has used N_e concepts since it first included threatened animal breeds as an indicator. Livestock breeds have been considered as threatened or endangered based on N_e thresholds since at least 1992, when $N_e < 200$ was used to signal genetic erosion (Maijala 1992). N_e features prominently and is explained in detail in numerous Food and Agriculture Organization manuals, and the US endangered species recovery planning, the zoo community, and others are also already utilizing N_e for monitoring genetic diversity.

(4) Although $N_e/N_c \approx 0.1$ is an appropriate general estimate, Frankham and we ourselves are mindful that there is substantial variation; Frankham et al. (2019) provide a thorough analysis in this context. The indicator $N_e > 500$ represents a reminder that maintaining genetic diversity within populations can sometimes require smaller or larger census sizes than $N_c = 5000$, and allows the use of adequate N_e/N_c estimates when available.

(5) N_c can be even more difficult to estimate than N_e, e.g. in many mobile, nocturnal, subterranean, or otherwise hard to count organisms.

Frankham (2021) rightly states that N_e can be complex, but theoretical developments and simulated and empirical data are consistently improving our knowledge and tools (Hössjer et al. 2016; Wang 2016; Ryman et al. 2019; Santiago et al. 2020). Our approach allows new information to be used to adjust N_e/N_c. In addition, the relationship between ploidy level and loss of diversity is likely not as straightforward as suggested by Frankham. For example,

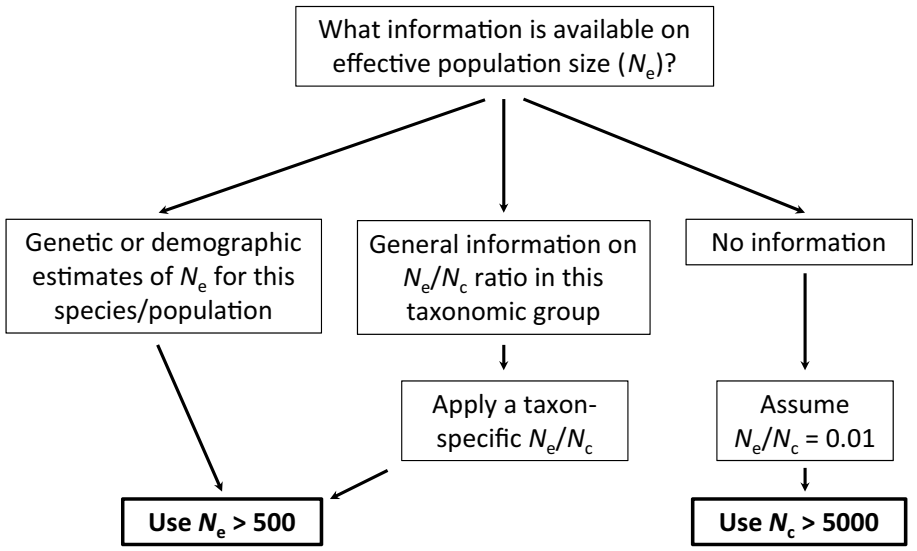

Fig. 1 Conceptual diagram for applying the N_e indicator (Hoban et al. 2020). If direct and robust estimates of N_e are available, they should be used. If only general information is available about factors affecting the ratio of N_e to census population size (N_c), then this information should be used to calibrate estimates of N_c from the specific population against the $N_e > 500$ threshold. If no information is available, the indicator is applied using estimates of N_c with the threshold $N_c > 5000$, implicitly assuming $N_e/N_c = 0.1$

approximately 50% of all plant species are polyploids, and most, but not all, polyploids lose diversity at the same rate ($1/2N_e$) as diploids (Soltis and Soltis 2000).

Conservation geneticists worldwide are working together to rapidly provide science-based guidelines for Goals, Targets, and Indicators for the post-2020 CBD framework. The Species Information Centre at the Swedish University of Agricultural Sciences has agreed to test indicators 1 and 2 (Hoban et al. 2020) on taxa from the Swedish Red List, and a G-BiKE (https://sites.google.com/fmach.it/g-bike-genetics-eu/home) working group is compiling data on indicator 3. We look forward to collaborating with Frankham and others to achieve improved CBD indicators for genetic diversity. Genetic diversity must be conserved as a foundation for all biodiversity, adaptive potential, resilience and nature's contributions to society.

Acknowledgments We acknowledge ongoing collaboration with the GEO BON Genetic Composition Working Group, the IUCN Conservation Genetics Specialist Group, the Society for Conservation Biology Conservation Genetics Working Group, and the EU Cost Action Genomic Biodiversity Knowledge for Resilient Ecosystems (G-BiKE). This publication is based upon work from COST Action G-BiKE, supported by COST (European Cooperation in Science and Technology). VR and Formas supported L.L. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the United States Government.

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