Uttam Kumar Rai/Our Nature (2003) 1: 3-9

Minimum Sizes for Viable Population and Conservation Biology

Uttam Kumar Rai
Columbus State University, Georgia, USA
Email:raiuttam@yahoo.com

Abstract

Minimum viable population size implies that there is some threshold for the number of individuals that will ensure at some acceptable level of risk that a population will persist in a viable state for a given interval of time. Fundamental to this concept is the effective population size. The so-called 50/500 rules have been criticized and a reliable minimum size for viable population is hard to obtain. However, this concept is indispensable in ex situ conservation programs like captive breeding. Minimum area requirement can be deduced for reserve plans. Discussions generated by minimum viable population size concept give insights into conservation biology.

Keywords: Minimum viable population, Conservation, Effective population size

Introduction

The concept of minimum size for viable population has received considerable attention in conservation biology. Minimum viable population (MVP) size implies that there is some threshold for the number of individuals that will ensure (at some acceptable level risk) that a population will persist in a viable state for a given interval of time. Genetic consideration and evolutionary consideration lead to two predictions concerning MVP. Effective sizes of 50 and 500 individuals were suggested by Soule (1980) for short term and by Franklin (1980) for long-term survival respectively. This 50/500 rule has been criticized and MVP has been ridiculed for its application in the wild by Caughley (1994) and Henriksen (1997). The MVP has lost its importance as a management goal in conservation but as a management tool, still has useful aspects. In this paper, I choose to highlight some of the useful aspects of MVP to show that it still has a role to play in conservation biology.

Minimum Viable Population Size

The idea that small populations are more vulnerable to extinction can be found in the work of MacArthur and Wilson's (1967) Theory of Island Biogeography. They proposed a model, which indicates that the probability of extinction varies with population size. An isolated island represents equilibrium between the number of immigrating species and number of species becoming extinct. Smaller islands have less number of species and, more important, smaller populations will have shorter time to extinction. This model implies that below a certain threshold population size of individuals for island species the expected time to extinction will be very short. And above that threshold the population will have relatively longer time of persistence. Shaffer (1981) defined MVP for any given species in any given habitat as the smallest isolated population having a 99% chance of remaining extant for 1000 years despite the foreseeable effects of demographic, environmental, genetic stochasticity, and natural catastrophes. Thus to avoid extinctions, the population must be sufficient to withstand such random events. Demographic stochasticity includes random factors that affect the birth rate and the death rate of population. If more animals die and few animals born, extinction can occur before the population can recruit themselves to a safe number again. Random variation in sex ratio and reproductive successes in females also lead population to decline and extinction. The effect of demographic stochasticity is greatest in small populations. Environmental stochasticity includes variations that are external to the population like rainfall, temperature, availability of food, and population of competitors, predators and diseases. Environmental stochasticity affects the population by influencing the demographic parameters. Natural catastrophes include fires, floods, earthquakes, and volcanic eruptions. Genetic stochasticity refers to the random processes involved in passing genes from one generation to the next. Genes may be lost from a small population and the gene frequencies may be changed due to drift or inbreeding.

Effective Population Size

The concept of effective population size is fundamental to MVP size. The effective population size is the actual number of individuals that can breed to produce viable offspring. In other words the effective population size is the ideal population, which is able to maintain the same genetic diversity as the real population. Therefore, it is always necessary to find out the effective population number before the MVP size for that population can be estimated. The effective population size takes into several basic assumptions (Mace 1986):- a) random mating, b) no migration, c) no mutation, d) no selection, and e) non-overlapping generation. If any of these assumptions are violated in a population, the effective population size will differ from the census population size. In the real world, a population will almost never follow all the above assumptions at the same time and therefore the census population is usually greater than the effective population size. A census population consisting of the effective population size to avoid extinction over a given time is taken as the MVP for that population. Simberloff (1988) has pointed out two types of effective population size- the inbreeding effective population size, and the variance effective population size. The inbreeding effective population size is the size of an ideal population with the same rate of decrease in homozygosity as in the particular population, while the variance effective population size is the size of an ideal population with the same rate of variance due to drift as in the particular population. These two population sizes can be similar when population size is constant, and sometimes can be different. In a growing population the variance effective population will tend to be greater than inbreeding effective population size. In a declining population, the opposite occurs. In addition to random mating, no migration, no mutation, no selection and non-overlapping generation, the effective population size will also vary because of different mating behaviors in monogamous and polygamous system.

The Magic Number

Michael Soule (1980) directly addresses the question of MVP size by asking what minimum size a population must have in order to prevent extinction. Animal breeders generally agree that domestic animals are able to tolerate inbreeding levels of two or three percent before there is a decline in performance and fertility. Applying this to natural populations, Soule observed that: 1) domesticated stocks have been partly purged of deleterious genes over the millennia, so they can tolerate higher rates of inbreeding than can outbreeding species from the wild, and, 2) animal breeders can safely ignore some classes of phenotypic change resulting from inbreeding and genetic drift. Due to these factors, Soule fixed a maximum accepted value of inbreeding at 1% per generation and calculated a value of 50 as the effective population size. He thus came up with the minimum effective population size for persistence of a population as 50 individuals. This effective population is only for a short term persistence and is not intended to apply for time spans greater than 100 years because there will be a continual genetic variation over time. This drop in genetic variation could then result in the demise of a population despite a constant effective population size of 50.

Franklin (1980) applied this concept to a longer time frame. He suggested that in the long term, genetic variability will be maintained only if population sizes are an order of magnitude higher than 50. This is based on the assumptions that continued and rapid evolutionary change is necessary for populations and species survival, and that response to natural selection is limited by small population sizes. Due to this, Franklin suggested that in the short term, the effective population size should not be below 50. More importantly, he proposed that for long term the effective size should be 500 in order to account for the expected rapid loss of genetic variance. Hence, the census population that consists of 50 and 500 effective populations have been taken as the MVP sizes for short and long-term persistence respectively. Below this size, populations will decline and fall into the extinction vortices described by Gilpin and Soule (1986).

The MVP size is a genetically based concept and has been often estimated by using simulation models. A common method employed is the population viability analysis (PVA). Conceptually, MVP and PVA are intimately linked. PVA aims to establish a minimum viable population that reduces the risk of extinction to an acceptable level (Henriksen 1997). That is, PVA is the process and MVP is the product. Using this method, Nantel *et. al.* (1996) estimated the MVP of the American Ginseng (*Panax quinquefolium*) and the Wild Leek (*Allium tricoccum*) in Canada. The extinction thresholds for the ginseng, described as the minimum number of plants needed to rebuild a population, varied from 30 to 90 plants. And the MVP size was estimated at 170 plants to remain extant for 100 years. For the leek the extinction threshold was estimated at 140-180 plants and the MVP at 300 to 1030 plants depending on the threshold chosen. Another study by Berger (1990) of the Bighorn Sheep (*Ovis canadensis*) was able to show that extinctions were related to initial population size and persistence time were longer for larger population (100 sheep) and shorter for smaller population (less than 50 sheep). It shows that sheep populations below 50 individuals are unable to resist rapid extinction and a population of at least 100 individuals is necessary. Kinnaird and O'Brien (1991) used genetic and demographic models of PVA for the Tana River Mangabey

(*Cercocebus galeritus galeritus*). They calculated for an effective population size of 500, the census population has to be 3600-4500 individuals. To assure a 95% probability of population persistence over the next 100 years, a population of nearly 8000 individuals was necessary.

Discussion

The magic numbers and along with them, the MVP, has been heavily criticized and has, as a result, lost importance as management goals. The 50 rules are based on empirical studies from population in captivity. Lande (1995) has pointed out that wild animals are less likely to tolerate inbreeding than domestic ones. Therefore wild animals will fall into inbreeding depression quicker. He also estimated 5000 individuals as the effective population size necessary to maintain genetic variation for the long term, rather than the proposed 500. This suggests that to maintain a genetically healthy and viable population, it is necessary to secure a much larger population size than the existing population of many of today's endangered species.

The relationship between effective population size and decrease in genetic variability is well understood but the relationship between variability and population viability is not. The MVP size will likely vary widely from 500 due to differences in inherent variability among species, demographic constraints or the evolutionary history of a population's structure. Most important, the simple maintenance of a certain effective population size will not guarantee long-term preservation of variability due to the influence of stochastic environmental and demographic effects on the size, composition, and thus genetic makeup of a population. Lande (1988, 1995) suggest that demography is usually of more immediate importance than population genetics in determining the minimum viable sizes of wild populations. Caughley (1994) has also criticized the 50/500 rules for being based on purely genetics, which, in his words, "have nothing to do with the size of a caribou population sufficient to cope with freezing rain in two successive years." There can be no single magic number for the minimum size of populations subject to varying influences on their dynamics. And if generating one is possible, it can be done only after accumulation of case studies and experimental manipulation of population's size (Boyce 1992). Caughley (1994) placed the MVP concept within the small-population paradigm that, according to him, is purely theoretical and its link to actuality poorly developed and contributes insignificantly to conservation goals. That is true. But on the other hand, even when MVP sizes as management goals for wild populations may not seem directly appropriate, one has to admit they are important for planning and designing reserves. MVP has wide application to small and fragmented populations outside a reserve system like captive breeding program. Captive breeding is one of the most powerful tools available for rescuing a species that has declined to very low density. Captive-bred populations can be highly managed and all the necessary data of the individual's life history can be gathered and documented. Hence, unlike the wild populations, relatively accurate estimation of the effective population and MVP sizes can be obtained. The first efforts at captive breeding were usually to produce as many offspring as possible. Population genetics has guided this blind propagation approach to a more cautious and planned breeding program. Modern captive breeding programs aim at preserving genetic diversity and focus into such strategies as to ensure the long term conservation of endangered species by maintaining the species adaptive potential. Initial rapid expansion of captive populations is necessary, however as soon as the population is secure, constraints placed upon rapid growth by management initiatives should be established. Once at carrying capacity, the growth rate of the population should be minimized as much as possible, thereby increasing generation time and reducing losses in heterozygosity. This is not to say that captive breeding must be undertaken immediately as the first step to bring back population to secure numbers. This approach is very resource demanding and can be provided for a very small number of species. It is often the last hope for species recovery and restoration when population has declined steeply.

Questions about populations falling below their MVP size might be abandoned as hopeless cases have raised important issues. For such populations immediate steps have to be taken. Intervention is one such step. This is where genetics considerations will prove critical. No doubt, genetics may not predict the likelihood of the caribou population surviving two consecutive harsh winters but what then if the population really dies of cold and only a handful remain ? Will they be able to bounce back on their own or is some kind of intervention required? Species conservation is not a simple task. An amazing number of factors govern whether a population persists or become doomed with extinction. Neither demography nor genetics alone will solve the problem completely; nonetheless each contributes a further understanding of the challenges we face in species conservation.

MVP size provides valuable hints for designing reserves. Among other things that are critical to designing protected areas, an important question is the size of the reserve. The long debated matter as to whether a single large or several small (SLOSS) reserves would be preferable can draw valuable insights from the concept of MVP size. An MVP size requires a minimum area requirement (MAR) in order for the population to persist. Reserve managers have to accept the risk that a small population will face extinction even after its habitat is protected. If a refuge contains all of the habitats necessary for all species of concern, quick extinction might occur if the reserve size cannot maintain the MVP. There might be a tendency not to establish a reserve if a sufficiently large reserve cannot be acquired because of the huge amount of resource and efforts applied will not meet the conservation goals. But then again, it can drive planners to look for other possibilities and how the MAR can be obtained for the population at risk. Howells and Edwardsjones (1997) provide a good exemplary case. They estimated an MVP size at 300 individuals of wild boar (*Sus scrofa*) was necessary if the reintroduction to the Scotland woodland was to be successful. The MVP size was identified as having a probability of greater than 95% of surviving for 50 years. But the suitability of separate three largest woodlands was not considered large enough to support 300 wild boars. Joining these three woodlands into a single large habitat could attain the MAR and harbor the MVP for reintroduction.

Instead of reintroducing the exact MVP size of individuals it is better to be cautious as to how less individuals should not be replaced. Much has already been said about the arbitrary definition of MVP, and yet the importance of putting in more individuals than the actual MVP size seems desirable if one wishes to remain on the safer side. This means larger reserves are better able to maintain the population viability as opposed to several smaller that are just sufficient to support an MVP size. For large predators and wide ranging species, an MVP size indicates the necessity for very huge reserves that might not be easy to acquire (Soule and Simberloff 1986). However, if such large reserves capable of maintaining viable population of large predators can be established, then it will automatically protect a large number of other species as well.

MVP concept also lends help to small fragmented landscapes. In an isolated small population, estimation of the MVP allows reserve managers to plan for corridors or translocating subpopulations. Such measures to enhance movement between subpopulations prevent loss of heterozygosity. In a small isolated population of the Acorn Woodpecker (*Melanes formicivorus*), the persistence time improved from 49 years to 1000 years when 5 individuals immigrated annually from another subpopulation (Stacey and Taper 1992). The MVP concept has been extended to metapopulation. Hanski *et al.* (1996) describes the minimum viable metapopulation (MVM) as the minimum number of interacting local populations necessary for long-term persistence of a metapopulation in a balance between local extinction and recolonization. And the minimum amount of suitable habitat (MASH) is the minimum density (or number) of suitable habitat patches necessary for metapopulation persistence.

Conclusion

It is agreeable that MVP is a slippery notion as Caughley (1994) noted. The definition is arbitrary in describing the number of individuals' probability of persisting over an assumed number of years. So is conservation itself because populations ultimately become extinct. Conservation is a necessity today to protect species from anthropogenic ally induced extinction. The point is that conservation efforts require setting their goals to measure success, which is difficult to quantify in absolute terms. Incorporating each and every factors pertaining to extinction or persistence into planning is very difficult. Conservation science is a new field and the act of conserving species is a very complex business. In this sense, rather than undermining MVP for its failure to provide quick simple numbers, it will be only fair to appreciate some of its better sides. First, it is always helpful to keep MVP in mind because it constantly suggests that there are critical aspects of populations like size, distribution or genetics that governs the probabilistic march towards extinction. Second, it brings to mind that small populations are in imminent need of extra attention than the larger population and directs conservation efforts to specific goal. Third, MVP size generates the MAR concept. This is useful in helping reserve managers or planners in designing protected areas. Fourth, it highlights the significance of metapopulation in the conservation field. Fifth, it is indispensable in zoos and in other captive breeding programs.

MVP has given valuable insights to conservation biology. Many questions raised regarding the minimum sizes and magic numbers have helped in the reconsiderations of various aspects of conservation. I wish to conclude with a quote by Simberloff (1988), "If science advances by testing and refuting hypothesis, conservation science has clearly advanced quite a way. It is certainly clearer now than before exactly what aspects of species' biology must know more about in order to conserve it."

References

Berger, J. 1990. Persistence of different sized populations: an empirical assessment of rapid extinctions in Bighorn Sheep. *Conservation Biology* **4:** 91-98.

Boyce, M. S. 1992. Population viability analysis. *Annual Review of Ecology and Systematics* **23:** 481-506.

Caughley, G. 1994. Directions in conservation biology. *Journal of Animal Ecology* **63:** 215-244.

Franklin, I. R. 1980. *Evolutionary change in small populations*. pp. 135-149.

Gilpin, M. E. and M. E. Soule 1986. Minimum viable populations: processes of species extinction. In *Conservation biology: the science of scarcity and diversity* (Eds. M. E. Soule). Sinauer Associates, Sunderland, Massachusetts. pp.19-34

Hanski, I., A. Moilanen and M. Gyllenberg 1996. Minimum viable metapopulation size. *The American Naturalist* ***147**:* 527-541.

Henriksen, G. 1997. A scientific examination and critique of minimum viable population size. *Faunanorv.* ***18*****:** 33-41.

Howells, O. and G. Edwardsjones 1997. A feasibility study of reintroducing wild boar (*Sus scrofa*) to Scotland- are existing woodlands large enough to support minimum viable population ? *Biological Conservation* ***81*****:** 77-89.

Kinnaird, M. F. and T. G. O'Brien 1991. Viable populations for an endangered forest primate, the Tana River Mangabey (*Cercocebus galeritus galeritus*). *Conservation Biology* ***5*****:** 203-213.

Lande, R. 1988. Genetics and demography in biological conservation. *Science* ***241*****:** 1455-1460.

Lande, R. 1995. Mutation and conservation. *Conservation Biology* ***9*****:** 782-791.

Mac Arthur, R. H. and E. O. Wilson 1967. *The theory of island biogeography*. Princeton University Press, Princeton, New Jersey.

Mace, G. M. 1986. Genetic management of small populations. *Int. Zoo. Ybk.* ***24*****(*****25*****):** 167-174.

Nantel, P., D. Gagnon and A. Nault 1996. Population viability analysis of American Ginseng and Wild Leek harvested in stochastic environments. *Conservation Biology* ***10*****:** 608-621.

Shaffer, M. L. 1981. Minimum population sizes for species conservation.*BioScience* ***31*****:** 131-134.

Simberloff, D. 1988. The contribution of population and community biology to conservation science. *Annual Review of Ecology and Systematics****19*****:** 473-511.

Soule, M. E. 1980. Thresholds for survival: maintaining fitness and evolutionary potential. In *Conservation biology: an evolutionary-ecological perspective* (Eds. M. E. Soule and B. A. Wilcox) Sinauer Associates, Sunderland, Massachusetts. pp.151-169

Soule, M. E. and D. Simberloff 1986. What do genetics and ecology tell us about the design of nature reserves? *Biological Conservation* ***35*****:** 19-40.

Stacy, P. B. and M. Taper 1992. Environmental variations and the persistence of small populations. *Ecological Applications* ***2*****:** 18-29