What is inbreeding, what factors influence it and why is it such a problem in rare or threatened species in in-situ and ex-situ conservation programmes?

Inbreeding is defined by some as *"the production of offspring from individuals related by descent"*. This includes a range of biological relation such as parent-offspring mating, mating between cousins and self-fertilisation. Inbreeding in animal and plant populations generally leads to a negative effect known as inbreeding depression whereby there is a reduction in reproductive fitness due to the reductions in heterozygosity. Heterozygotes mask deleterious recessive alleles but homozygotes do not, so the increased proportion of homozygotes in an inbred population result in accumulation of these deleterious alleles. This results in reduced genetic diversity, which can be damaging because there there is less of a chance that individuals will possess genotypes promoting survival following a change in biotic and abiotic conditions. This can prove to be a great problem for rare and threatened species with small populations as it can lead to an extinction vortex whereby populations rapidly go extinct because they possess the same genotypes that are not appropriate for survival in the current or upon a change in conditions. It may be that the deleterious mutations reduce fitness by actively causing morphological or physiological impediments, or that the loss in polymorphism across the population reduces the likelihood of survival upon a change in environmental conditions or emergence of disease *(Frankham R et al, 2010)*. This essay will specifically look at the factors that influence inbreeding as well as the problems that arise following it by looking at examples of plant and animal populations.

Factors Influencing Inbreeding

The level of inbreeding and its negative effects in a population may be influenced by a variety of factors, such as population size, mutation rates, level of selfing in plant species, bottlenecks or intensity of selection for or against heterozygotes or homozygotes *(Hedrick PW et al, 1999)*. One of the major factors that commonly influences inbreeding within populations are when said population is unusually small. This is because, naturally, over time individuals within this population will become related by descent. This can result in an exponential increase in inbreeding and a simultaneous decrease in population size because as the size is reduced, the rate of inbreeding will continually increase. An example of when there are small population sizes is when a community experiences a bottleneck. Bottlenecks can be defined as *"a sharp reduction in population size [that may be] short or long term"*. They may occur after a natural mass extinction event or by result of human activities. Another example of when there may be a small population thus resulting in an increase in inbreeding is as a result of the founder effect. This can be defined as the *"change in genetic composition of a population due to origin from a small sample of individuals"*. Therefore, as stated, the founder effect is when a new community of species arises from a single small population, which may result, for example, from a small colonising group that settles within a new area due to population flow into an isolated region. Because of the original small population, this means that the resulting community have reduced genetic diversity, therefore leading to increased inbreeding *(Frankham R et al, 2010)*.

Another factor that can influence the rates of inbreeding is the interaction and flow between different populations. This is because the flow of different individuals from a population to another results in the introduction of more genetic diversity. Therefore, if a population does not experience the flow of more individuals into it, it may become genetically isolated, therefore leading to an increased rate in inbreeding due to the relatedness of the individuals over time. The effect of isolation between animal species populations and its effects on inbreeding can be observed in the communities of Florida panthers. Due to human activity, particularly urbanisation, the range of these individuals has been greatly reduced and to the point where the flow between communities has forcefully been halted. This has resulted in demographic reduction and thus an increase in inbreeding depression due to the factors discussed above. Specifically, through the increase in deleterious alleles the panther species inherit spermatozoal defects such that their sperm is less motile and more likely to be malformed. As well as this, through inbreeding the incidence of Cryptorchidism has increased, characterised by undeveloped testicles and thus a reduced rate of spermatogenesis. These changes linked to negative traits within the male reproductive system are associated with recessive alleles that increase in homozygotic frequency through the process inbreeding. The population of Florida panthers in 1993 consisted of just 30 individuals whereby inbreeding was impossible to avoid to the point where in order to increase genetic diversity new individuals had to be introduced *(Roelke ME et al, 1993).*

The connectivity between populations and its effects on inbreeding is also conversely demonstrated by studies on rhododendron populations. Despite the fact there is only two populations of the world's largest rhododendron, gene flow between the two occurs by the transfer of pollen by insect species and seed dispersal. Therefore, inbreeding depression is avoided because gene flow is sufficient in helping maintain genetic diversity of the two populations *(Wu FQ et al, 2014).*

The final factor discussed in this essay that affects the rate of inbreeding in populations is the occurrence of regular systems of inbreeding in the normal population dynamics of a community. In many plant species, self-fertilisation is common as a strategy to produce offspring when there is a lack of potential reproductive mates within the immediate habitat. This natural rate varies between different plant species. Although this may be an effective short-term strategy, due to its status as a form of inbreeding, in the long term it has adverse negative effects on the genetic diversity of a population *(Frankham R et al, 2010).*

Why is inbreeding such a problem?

As previously discussed, inbreeding can cause an array of consequences that have a negative effect on an individual and wider level. This includes reduced genetic diversity, which leads to a lack of adaptability and variation as well as the potential for abnormalities to arise. As discussed, inbreeding can also lead to extinction vortices where the offspring of a small population are likely to inbreed leading to reduced fitness and therefore an even more diminished population size *(Frankham R et al, 2010).*

These problems can be observed in a variety of plant and animal populations in wild populations as well as those in in-situ and ex-situ conservation programs. One of the most studied cases where inbreeding has had a significant negative effect on a population is in Tasmanian devil populations in Australia. These are a carnivorous marsupial species that historically experienced a population bottleneck and geographical fragmentation thus resulting in a current genetically isolated population. This has resulted in inbreeding within the population leading to a substantial reduction in polymorphisms in the major histocompatibility complex (MHC), which provides resistance to infectious diseases whilst successfully discriminating between self and non-self. Therefore, Tasmanian devils often have an inability to respond to specific infections from certain pathogens. Namely, the species has an inability of recognizing face tumours as foreign and therefore the cells uncontrollably divide. The Tasmanian devils are therefore susceptible to Devil Face Tumour Disease (DFTD), which actively causes a decrease in fitness and can lead to direct death or mortality through secondary infection or the incapability to feed. The disease spreads rapidly through the population because it is determined by mating interactions as opposed to density dependence. This spread has led to a population decline of over 60% leading to an estimate that the entire population is likely to be affected in five to ten years *(McCallum H, 2008)*.

Various conservation strategies have been introduced in order to maintain the population of devils and attempt to uphold the genetic diversity. This includes ex-situ strategies whereby uninfected individuals are put into captivity and the mating between them is carefully controlled to promote the optimal increase in genetic diversity. Alternatively, in-situ methods can be used where physical barriers are constructed to obstruct contact between infected and non-infected individuals *(McCallum H, 2008)*.

Another example where inbreeding has caused biological problems is in the plant species *Rutidosis leptorrhynchoides*. The individuals within this species, and within the entire family, have incompatibility systems whereby self-pollination (or pollination between closely related individuals) is prevented due to the presence of the same incompatibility alleles. Despite this, when the population decreases, the genetic diversity of the self-incompatibility locus also is reduced, in turn leading to a reduction in the number of available mates. Population will continue to decline until a threshold is reached where the system fails and self-pollination is permitted. This results in inbreeding leading to adverse negative effects often associated with monocultures. This means that all of the plants in the population are in danger of going extinct upon a change in environmental conditions or upon the introduction of a new pathogen. To counteract this negative effect, a form of conservation may involve the introduction of genetic material from different populations in order to increase appropriate mate availability *(Pickup M & Young AG, 2008)*.

Conclusion

Inbreeding is a biological phenomenon that may occur due to a variety of different factors. Ultimately, it reduces the fitness of a population such that it is more likely to go extinct in the near future. Conservation strategies must therefore be put in place in order to control the genetic diversity within these populations. However, the correct balance within in-situ and ex-situ conservation may be difficult to achieve in terms of benefits to the species' genetic diversity and population versus other adverse biological effects. Inbreeding is therefore best controlled by using conservation methods that prevent the emergence of the issues before population size and genetic diversity decreases.

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