Securing the Future of the Canaan Dog: Five Challenges and a Path Forward

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Securing the Future of the Canaan Dog: Five Challenges and a Path Forward

Abstract

The global Canaan Dog population is facing a critical situation. Although census numbers appear stable, the effective population size (N_e) is far below conservation thresholds and further reduced by the division into two largely isolated regional subpopulations. This article examines five major challenges that threaten the long-term survival of the Canaan Dog as a healthy, genetically diverse, and functionally stable breed: the critically low effective population size, the need to expand genetic diversity, the management of hereditary health risks in the age of genetic testing, puppy placement in a critically small breed, and the recruitment of new breeders. Drawing on current data, population genetics, and practical breeding experience, the article outlines evidence-based strategies to increase genetic diversity, reduce inbreeding, and pathways to stabilise the breed for future generations. It is intended as a scientifically informed guide for breeders, clubs, decision-makers, and all Canaan Dog lovers committed to securing the future of our breed.

Introduction

The Canaan Dog originates from an indigenous landrace that evolved naturally in Israel under harsh conditions. While it has been bred within formal standards for some decades now, it has not undergone the intensive artificial selection that is typical of modern breeds. Breeding efforts have focused on conserving the naturally occurring dog, helped by the introduction of free-living dogs from the region under increasingly difficult circumstances.

This unique history has produced a breed with remarkable resilience, behavioural distinctiveness, and a genetic profile that differs fundamentally from that of most modern purebred dogs. However, ongoing conflicts in its region of origin and developments in modern society in general are further narrowing the niches where the Canaan dog can find its place. As a consequence, the breed now faces a set of challenges that threaten its long-term viability as a healthy and genetically stable breed.

Superficially, the global population appears just about adequate in terms of number. However, a closer examination of the breeding population reveals a far more fragile situation. The effective population size (N_e) is critically low, and the breed is divided into two geographically and genetically semi-isolated subpopulations in the United States and Europe/Israel/UK. This structural division, combined with a limited founder base, inbreeding, and global challenges felt by us all, places the breed at significant risk of functional extinction.

At the same time, modern genetic testing has introduced both opportunities and uncertainties. While some tests — such as those for Degenerative Myelopathy — provide actionable information, others lack validation in the Canaan Dog and risk misinterpretation, resulting in unnecessary selection. Varying breed standards leave further room for over-selection that may harm the breed's genetic diversity.

This article has three primary aims:

1. To provide a data-driven overview of the current status of the Canaan Dog from a conservation point of view.

2. To identify the five key challenges that should be addressed to preserve the breed's long-term health and viability.
3. To outline practical, scientifically grounded strategies to increase genetic diversity, manage health risks, and stabilise the population of the breed.

The following chapters are intended not only to inform but also to encourage responsible, coordinated action. The future of the Canaan Dog depends on the decisions we make today — decisions that must balance genetic conservation, health, breeding infrastructure, and the preservation of our breed's unique identity.

A heartfelt thank you to our fellow breeders, who were all happy to share their data.

1. Challenge #1: Effective population size of the Canaan Dog breed

In animal conservation, a species is considered functionally extinct when individuals still exist but the population can no longer perform its ecological role, e.g. when there are too few examples to impact pollination or seed dispersal, or when the species can no longer sustain a viable population. This may occur when numbers fall so low that genetic bottlenecks, inbreeding depression, or genetic drift undermine long-term viability.

A similar concept applies to dog breeds. A breed becomes functionally extinct when it can no longer reproduce itself as a stable, distinct breed anymore. In other words, there may still be a number of dogs with a "Canaan Dog" pedigree, but there are not enough purebred, genetically viable and healthy individuals to sustain the breed into the future. This typically happens when:

- There are too few purebred individuals to maintain genetic diversity.
- The remaining dogs have become too crossbred to preserve the breed's phenotype and genetic identity.
- The breed no longer serves its original purpose and has not found a new one, causing its role to disappear or to be taken over by other breeds (e.g., the English Water Spaniel).

As a result, even if a few dogs remain alive, the last breeding lines eventually collapse.

1.1 Census population vs. breeding population

For long-term survival, what matters is not how many Canaan Dogs exist in total (the census population) but how many are actually used for breeding (the breeding population). In most purebred dog populations, only a small fraction of living dogs ever reproduce. This means the census number can look reassuring while the breeding population — the only group that contributes genes to the next generation — is critically small.

It should also be noted that breed census size does not predict inbreeding level; a breed with 100,000 registered dogs can be more inbred than a breed with 1,000 dogs.[1]

[1] Population Structure and Inbreeding From Pedigree Analysis of Purebred Dogs. Federico C F Calboli, Jeff Sampson, Neale Fretwell, David J Balding. Genetics. 2008 May;179(1):593–601. https://pmc.ncbi.nlm.nih.gov/articles/PMC2390636/

1.2 Why effective population size (N_e) is smaller than the number of breeding dogs

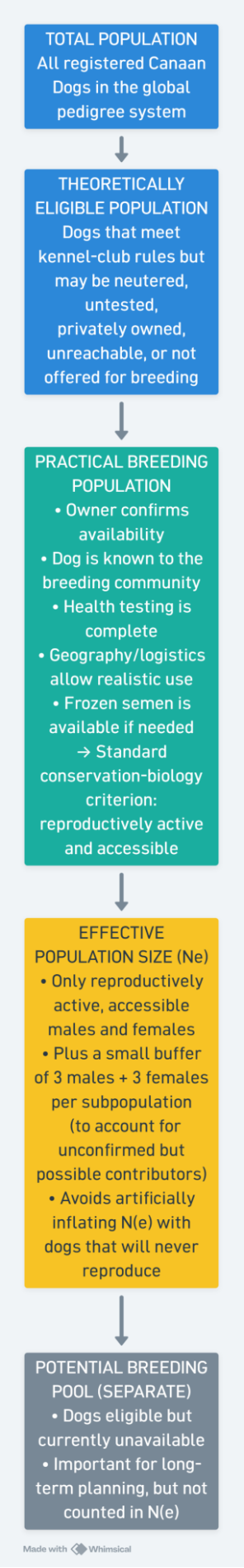
However, even the breeding population overestimates genetic security. The key metric is **effective population size (N_e)**, which reflects how many dogs *effectively* contribute to genetic diversity. Therefore, my survey counted only dogs whose breeders or owners confirmed availability, rather than all dogs technically eligible under kennel club rules, because N_e is not based on eligibility — it is based on realistic genetic contribution. A dog can only be counted towards the active breeding population if the owner is willing to make it available, the dog is known to the breeding community, and it can realistically be used given health testing, geography, and logistics including availability of frozen semen if necessary. Many Canaan Dogs across Europe and the US live with owners who are not involved in breeding, are unreachable by breeders, or have dogs that are neutered or untested. Counting them would artificially inflate the effective population size of the Canaan Dog and create a false sense of genetic security. Counting only reproductively active, accessible individuals when calculating N_e is standard practice in conservation biology.

To account for dogs that may exist outside established breeding networks, a small buffer of three males and three females was added per subpopulation. Adding more would have been scientifically unjustified, as most unconfirmed dogs will never reproduce. This approach mirrors endangered species management, where individuals count towards N_e only if they are reproductively active and accessible to the breeding programme. Dogs that are eligible but currently unavailable are not ignored — they form the potential breeding pool, which matters for long-term planning. But N_e must reflect what the population is actually doing, not what it could do under ideal circumstances.

Even when this strict distinction is applied, N_e is effectively reduced further because:

- Not all breeding dogs contribute equally.
- Some lines are overrepresented while others are underused.
- Popular sire and dam effects skew genetic input.
- Subpopulations (e.g., US vs. Europe/Israel/UK) breed mostly within themselves.

Even with balanced numbers of males and females, N_e is reduced whenever contributions are unequal — which is nearly always the case in real-world dog breeding. In the Canaan Dog, this reduction is intensified by the fact that the global breed is effectively split into two partially isolated subpopulations, one in the United States and one spanning Europe, the UK, and Israel. As a result, gene flow between them is limited and each group carries its own restricted genetic base.



Effective population size (N_e) especially matters for the Canaan Dog because:

- historical bottlenecks, including its small founder base, permanently constrain diversity
- inbreeding within closed studbooks increases relatedness so that even a seemingly sufficient breeding population behaves genetically like a much smaller one
- unequal sex ratios can concentrate genetic contribution in few lines
- large variance in reproductive success means some dogs produce many litters while others produce none
- non-random mating based on appearance, titles, or pedigree further restricts genetic mixing.

Because the two regional subpopulations rarely exchange breeding animals, each one experiences these effects independently and more strongly, which drives N_e down even further than in a single unified population.

As a result, even though the global census of breeding Canaans may look respectable, the effective population size of each subpopulation — and therefore of the breed as a whole — can be much smaller, because N_e captures the true genetic diversity and structure, not the headcount.

1.3 Current global breeding population of the Canaan Dog

If you had an equal contribution from breeding males and females, the common formula to calculate N_e would be:

$$N_e \approx \frac{4N_m N_f}{N_m + N_f}$$

where N_m= number of breeding males and N_f= number of breeding females.

Based on my recent survey across the US, Europe, Israel, and the UK, the worldwide breeding population consists of approximately:

- **34 breeding males**
- **29 breeding females**

For generosity, let us assume 40 males and 35 females. Using the standard formula:

$$N_e \approx \frac{4N_m N_f}{N_m + N_f}$$

we obtain:

$$N_e \approx \frac{4 \cdot 40 \cdot 35}{40 + 35} = \frac{5600}{75} = 74{,}67 \approx 75$$

This is an *idealised* estimate that assumes equal use of all breeding dogs — something that never occurs in practice. The real N_e of the Canaan Dog will be below this figure.

1.4 How Canaan Dog N_e compares to conservation thresholds

Conservation genetics uses the **50/500 rule**, or more realistically the **100/1000 rule**, as a baseline:

Threshold	*Purpose*	*Recommended Ne*
Short-term survival	Avoid rapid inbreeding depression	**50–100**
Long-term viability	Maintain evolutionary potential	**500–1000**

With an idealised effective population of $\mathbf{N_e \approx 75}$ — and the real N_e falling below that — the Canaan Dog sits just above the minimum short-term threshold and far below long-term requirements.

It should be noted that these thresholds are tailored to gauge the sustainability of populations in the wild, which face higher mortality rates in all periods of life than pedigree dogs. On the other hand, breeds with a low effective population size under human management face risks that wild populations do not.

1.5 Subpopulation structure further reduces N_e

The breed is effectively split into two subpopulations:

Region	*Breeding males*	*Breeding females*	***Total***
US	17	14	**31**
Europe/Israel/UK	17	15	**32**

If we treat these as partially isolated subpopulations (adding 3 males and 3 females to each for generosity), we obtain:

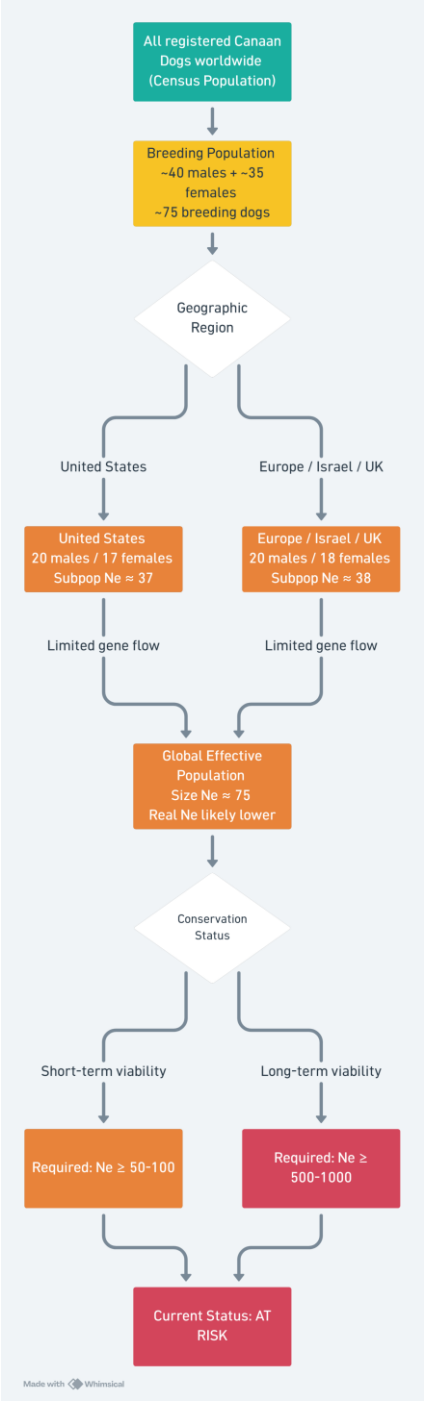
US: $N_e \approx \frac{4 \cdot 20 \cdot 17}{20+17} = \frac{1360}{37} = 36{,}76 \approx \mathbf{37}$

Europe: $N_e \approx \frac{4 \cdot 20 \cdot 18}{20+18} = \frac{1440}{38} = 37{,}89 \approx \mathbf{38}$

Both are far below the minimum of 50 needed to avoid rapid genetic drift and inbreeding.

Even when considering exchange of breeding dogs between regions, not all *theoretically* available Canaan Dogs will actually be used. This means the ***real*** **N_e is almost certainly below 60**.

One proven method to increase effective population size is to use a wider variety of males instead of relying only on the most popular ones. If 60-70% of available male Canaan Dogs sire at least one litter, we can expand our effective population size more quickly to get closer to 100.



1.6 How the popular sire effect affects N_e

The effective population size of a breed can be dramatically reduced by the **popular sire effect**. Consider a generation with 20 breeding males, 40 breeding females, and 40 litters total. If one popular sire fathers 20 of those litters while the remaining 19 sires share the other 20 equally, and females contribute evenly, the effective population size N(e) drops from approximately 53 — the value expected with equal male contributions — to just 25. A single overused sire has nearly halved the genetic effectiveness of the entire generation.

1.7 Conclusion

The effective population size of the Canaan Dog is near the bottom of the short-term safety threshold and far below any long-term security threshold. The number of Canaan Dogs currently available for breeding may be enough to keep the breed going for a while, but not enough to consider it genetically safe.

From a conservation perspective, the breed must be considered highly vulnerable. Without careful management, the Canaan Dog is on a trajectory toward functional extinction as a healthy, genetically diverse breed, even if it will not disappear numerically in the near future.

Therefore, our short-term goal should be to bring N_e closer to 100, and ideally toward 200–300 over time to achieve a sustainable long-term breeding population. There is hope, because my survey has also revealed that in addition to the dogs that are currently available and approved for breeding, we also have ca. 50 young Canaan Dogs with breeding potential in the starting blocks.

2. Challenge #2: Increasing genetic diversity

A breed with a limited pool of breeding dogs, especially one divided into two geographically distant subpopulations, is at constant risk of accumulating inbreeding. The level of inbreeding in a breed is shaped both by founder effects (how many unrelated dogs established the breed) and by historical and modern breeding practices (such as popular sires, closed lines, or geopolitical bottlenecks). As a result, a breed may be genetically constrained because of its past, even if current breeders are careful — and conversely, even a breed that began with good genetic diversity can become inbred if modern breeding practices narrow the gene pool.[2]

Of all the labs that do genetic testing, Embark (USA), which has tested more Canaan Dogs than any other laboratory, in recent times also a fair number of Canaans from Europe and some from Israel, reports an average genetic COI of **13%** for the breed. Compared to many other purebred populations, this is not catastrophic, but it still means that many theoretically available matings resemble pairings between first cousins or half-siblings.[3]

Therefore, our goal should be to reduce the genetic COI of the Canaan Dog below **10%** in the short term and ideally toward **5%** in the long term. Achieving this will be challenging given the breed's limited effective population size, but possible. The recommendation is to limit the use of each dog – not just males, but also females. No male or female should produce more than 5% of puppies born globally within any five-year window, limiting popular sire/dam effect. If we register ~500 puppies in 5 years, one male should not sire more than 5% = 25 puppies in that time window. These figures are general guidelines and should be consistent with most breed and kennel club limits.[4]

Our aim as a breeding community should also be to exchange 2–3 stud dogs per year between the US and Europe/Israel/the UK. Freezing semen to make stud dogs available for breeders abroad can further improve genetic diversity provided the dog is not already close to the 4-5% limit of puppies sired.

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[2] cf. 1

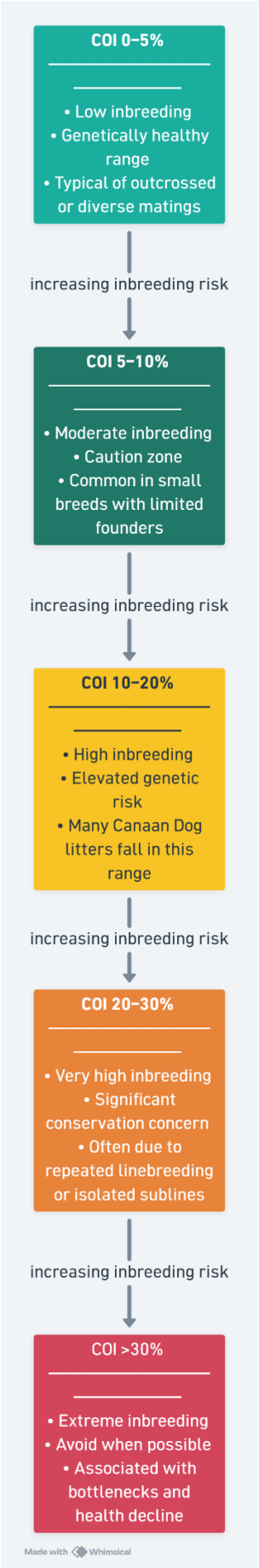
[3] A gCOI of ~6 % is equivalent of mating first cousins, while a gCOI of ~12-13 % would result from a mating of half-siblings. Breeding full siblings would typically produce puppies with a gCOI of ~25 %.

[4] The FCI International Breeding Strategies guidelines state that "no dog should have more offspring than equivalent to 5% of the number of puppies registered in the breed population during a five-year period." From the context, it is reasonable to conclude that this limit applies to both males and females. FCI International Breeding Strategies. https://www.fci.be/medias/ELE-REG-STR-en-451.pdf (download)

In addition, the Canaan Dog as a breed is fortunate in that the FCI still allows the controlled introduction of dogs from the wild through *miyun* (= selection). This gives us a rare opportunity to expand genetic diversity in a responsible and structured way.

For example, our young Canaan Dogs "Gil me Shaar Hagai" and "Gava me Shaar Hagai," both bred by Myrna Shiboleth and sired by the formerly free-living "Shaked ben Merhavim," have gCOIs of 2% and 1%. When bred to a full-pedigree Canaan Dog with a gCOI of around 10%, the resulting puppies are expected to have gCOIs of 5–6%. If Gava (1%) were bred to a pedigree male with a gCOI of around 7%, the predicted gCOI of the litter would be approximately 4%. These figures are based on Embark's Pair Predictor and on actual genetic testing.

Admittedly, the more dogs we use with a potentially more diverse genetic background, the greater the risk of producing offspring that may grow into a phenotype that pushes the limits of the breed standard, be it in size, head shape, ears, colour etc. This particular challenge can only be managed by thorough (self-)control as it is exerted by some national kennel or breed clubs, and by us as breeders through peer feedback. However, the introduction of free-living founder dogs remains a valid and valuable method to improve the genetic diversity of the Canaan Dog.



2.1 Pedigree-based tools and genetic COI testing

Pedigree-based COI tools, such as Wright's COI which we find printed on FCI pedigrees, can be useful but must be interpreted with caution. As a purely mathematical formula, Wright's COI simply predicts inbreeding based on the known common ancestors in the pedigree window assuming that the first generation in that window is completely unrelated (0% inbred), which is never true in a closed breed. It also cannot account for the base genetic COI of the dogs, i.e. for the breed-wide baseline homozygosity accumulated over many generations. As a result, Wright's COI always underestimates true inbreeding and should not be used as the sole decision-making tool.

The same is true for the metric often called Ancestor Loss Coefficient (ALC), which measures the proportion of ancestors missing from a pedigree due to repetition. ALC compares the number of unique ancestors to the number of ancestors that should exist if none were repeated. For example, in a **4-generation pedigree**, there are:

2 parents

4 grandparents

8 great-grandparents

16 great-great-grandparents

= 30 ancestors

However, let us assume the dog in our example only has 24 unique ancestors in 4 generations. The Ancestor Loss Coefficient for four generations is calculated by taking the number of unique ancestors actually present in the pedigree — in this case, 24 — and dividing it by the total number of ancestors that could theoretically exist in four generations — in this case, 30 — and then multiplying the result by 100 to convert it into a percentage. As a result, the dog has 80% unique ancestors and 20% ancestor loss (6 ancestors are repeated somewhere in the 4-generation pedigree).[5]

Again, ALC is a purely mathematical, pedigree-based measure. It reflects only the number of repeated ancestors in a pedigree but does not factor in the true genetics of the dogs, nor does it account for the baseline inbreeding level of the breed.

If no genomic data for the dogs in a mating is available, **mean kinship** (MK) calculations are more informative than Wright's OI and ALC because they consider the entire population rather than only the ancestors in a pedigree window. Mean kinship is the average genetic relatedness of an individual to the entire living population. A dog with low MK is less related to the population, so genetically valuable for conservation purposes. A dog with high MK is more related to the population, so it contributes less to the genetic diversity of the breed.

Utilising mean kinship as a breeding tool requires extensive pedigree data and appropriate software. The ongoing Canaan Dogs Database[6], curated by Blanka Kelisová (Kennel Sangro de Drago, Czech Republic) and others, is an important step in this direction. Systems like ZooEasy[7], which is used by zoos, animal parks and also the Dutch Kennel Club (Raad van Beheer), can calculate MK, but the cost of implementing such features is substantial. And again, MK is still a pedigree-based calculation and does not measure actual genomic variation.

While pedigree-based tools such as Wright's COI, ALC, and mean kinship (MK) each provide valuable information, genomic COI testing is the most accurate method for assessing the genetic diversity that puppies from a planned pairing are likely to inherit. Genomic COI measures real homozygosity across the genome, capturing cryptic relatedness that pedigrees miss. It is not limited by pedigree depth and cannot be thrown off by missing or incorrect pedigree data.

On the other hand, genetic COI does not tell us how rare or common an individual dog's genes are in the breed, whether its line is over-represented, or whether the pairing improves long-term diversity. So while genetic COI is the best measure to predict the true genetic diversity of puppies from a planned mating, mean kinship (MK) can complement our litter planning by identifying which dogs are genetically valuable at the population level, by showing whether the genes of the parents are common or rare in the entire living population of the breed.

There is an approach that combines genomic testing and population-based metrics, developed by the Veterinary Genetics Laboratory (VGL) at the University of California, Davis, and Dr. Niels C. Pedersen. While Embark estimates how much of a dog's genome is identical by descent so we can understand how inbred an individual dog is, VGL assesses the dog's Internal Relatedness (IR), i.e. its relative diversity within the breed's population, so we get a clearer picture of the dog's genetic diversity in relation to the rest of the breed.[8] This is why the same dog can show a moderate COI at Embark but a high IR at VGL, or vice versa.

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[5] $\mathrm{ALC_n} = \frac{\text{Number of unique ancestors in n generations}}{\text{Maximum possible ancestors in n generations}}$ x 100 where max. possible ancestors = $2^{n+1}-2$

[6] https://www.canaandogs-database.com/ (password protected)

[7] https://zooeasy.com/

[8] Embark uses SNP (single nucleotide polymorphisms) runs of homozygosity (ROH), whereas VGL UC Davis uses STR (short tandem repeat) microsatellite markers.

Embark and VGL both report a dog's DLA (Dog Leukocyte Antigen) haplotypes, which provide insight into how much immune-system diversity the dog — and the breed — still possesses. DLA haplotypes are inherited as intact blocks and cannot be recovered once lost, so their disappearance from a breed is effectively permanent without an outcross programme.

Because the testing performed by VGL aims to capture breed-specific DLA haplotype structures, and its genetic-diversity analysis also takes a breed-focused approach, it can be a valuable tool for a conservation programme — provided that a sufficient number of dogs from the breed have been tested. At present, the Canaan Dog is not among the breeds that can be tested or are in the research phase. Enrolling a breed for genetic-diversity testing at VGL requires an organised group of breeders committed to providing samples (preferably a minimum of 100 dogs as unrelated as possible) and funds for baseline testing (50 USD per sample).

There is one more caveat with regard to the genetic COI testing offered by Embark, MyDogDNA etc.: different laboratories use different reference populations and algorithms for gCOI, which complicates litter predictions when sire and dam are not tested by the same company. Embark offers both an automated Pair Predictor for dogs in a breeder's account and a manual prediction service for a pairing of one of your dogs with an external dog. Breeders can request this by emailing breeders@embarkvet.com with the registered names and swab or activation codes of both their own dog and the external dog, ideally copying the other owner to confirm permission.

Tool	**What it Measures**	**Strengths**	**Limitations**	**Best Use**
Genomic COI	Actual homozygosity across the genome (ROH)	Measures *real* genetic variation; detects cryptic relatedness; not limited by pedigree depth	Does not show population-level rarity; requires DNA testing	Predicting genetic diversity of *puppies* from a planned mating
Mean kinship (MK)	Average relatedness of a dog to the entire living population	Identifies genetically valuable low-MK dogs; guides conservation; population-wide	Pedigree-based; does not measure actual genomic variation	Choosing which dogs should contribute to the next generation
Pedigree COI (Wright's)	Expected inbreeding based on pedigree structure	Useful when genomic data is missing; detects close matings	Assumes founders unrelated; limited by pedigree depth; often underestimates true inbreeding	Screening matings without genomic data
Ancestor Loss Coefficient (ALC)	Pedigree collapse via repeated ancestors	Highlights structural bottlenecks; simple to compute	Purely mathematical; not a genetic measure; ignores true relatedness	Detecting repeated ancestors in shallow pedigrees

In practice, our breeding choices are always going to be limited not only by the numbers of dogs available and tested/approved for breeding, but also by practical reasons such as geographical distances, limitations on travel, the risk of AI being unsuccessful, costs etc. It is important, however, that we do not limit our breeding choices artificially — for example by breeding only for a certain colour.

2.2 Avoiding unnecessary exclusions

Colour genetics is an area where misunderstandings can easily lead to unnecessary exclusions. Because the Canaan Dog population is small, removing dogs from the gene pool for cosmetic reasons can have disproportionate consequences.

We have seen the potentially detrimental effect of breeding for colour in the German Klein- and Mittelspitz, whose populations are subdivided into three colour varieties as defined by its FCI standard. While other kennel clubs have allowed their breeders to mix the colours when mating, and then sort the puppies into the various colour categories afterwards, mating Spitz from different colour varieties has always been heavily restricted in Germany. Only now that some colour and size varieties are severely genetically bottlenecked and on the brink of being functionally extinct is mixing certain colours allowed by special permission. But it may already be too late.

We may also struggle with the fact that we have three breed standards for the Canaan Dog from the cooperating non-profit kennel clubs (FCI, AKC, Royal Kennel Club) plus a fourth one from the UKC. Even if we only had one unified breed standard, it might be tempting — and possible — to breed for a certain subtype of Canaan Dog, i.e. for a specific interpretation of the phenotype that we might personally prefer.

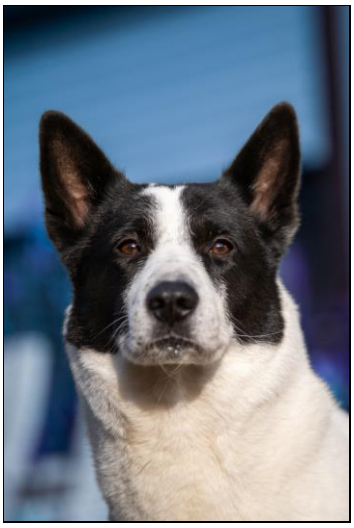
Further limitations to the effective population size and its genetic diversity might occur from removing dogs from the gene pool for faults that:

- are not disqualifying
- are not disqualifying in the breed standard of their supervising kennel club, but may be in others
- may be merely "cosmetic" aberrations but not genetically based problems
- are open to interpretation and may not constitute a disqualifying fault as intended by the breed standard.

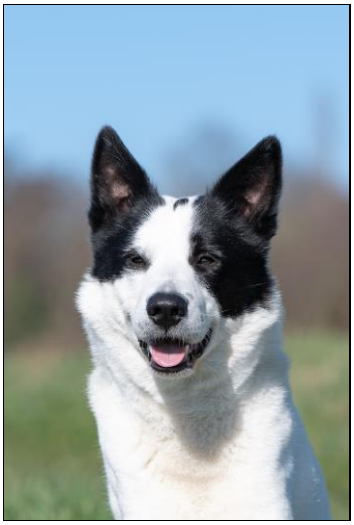
2.2.1 Masks

This is a particularly tricky challenge with regard to "masks", for example. Probably all of us would gravitate towards avoiding dogs with asymmetrical masks for breeding. The FCI standard states, "If masked, mask must be symmetrical." However, there is no scientific basis for excluding Canaan Dogs with asymmetrical masks from breeding, because science simply does not know what causes the mask on white/black or white/red Canaans. The mask in these Canaan Dogs is **not caused by the typical Em mask gene** on the E locus, which produces the classic mask in many other breeds, but a form of patterning determined by the S locus (piebald), possibly in combination with other yet unknown factors.

Here are some examples:



Symmetrical "mask" in the Canaan Dog, not caused by Em mask gene



Asymmetrical "mask" in the Canaan Dog, not caused by Em mask gene

Classical German Shepherd mask caused by Em mask gene[9]

[9] Photo by Dustin Bowdige on Unsplash. https://unsplash.com/photos/brown-and-black-german-shepherd-on-green-grass-field-during-daytime-qJ6VRRKJ-FE

INFOBOX 1: Key Coat Colour Loci in the Canaan Dog

E locus (extension)
- E = normal pigment
- Em = top dominant on E locus, but causes masks only in dogs that are *not* dominant black (see below)
- e = recessive red (e/e overrides most other colour genes)
- Eg = grizzle/domino (expression depends on K locus)

K locus (dominant black)
- Kb = dominant black
- ky = allows expression of other patterns
- Eg is only expressed in Kb/ky dogs

S locus (white spotting)
- Responsible for piebald patterns
- Likely interacts with mask appearance in white/black or white/red dogs

Because the genetic mechanism is not yet understood, there is no scientific basis for excluding dogs with asymmetrical masks from breeding. The mask is a cosmetic trait, not a health concern, and excluding such dogs would unnecessarily reduce genetic diversity.

2.2.2 Understanding "grey" in the Canaan Dog

Recently, we have seen more Canaan Dogs that do not simply appear sand-coloured but silver-grey, or shades in between. Early versions of the breed standard discouraged "grey", arguing:

"Grey specimens and black with brown legs are currently not desired in order to emphasize the difference to similar European sporting breeds." (original German: "Graue Exemplare und schwarze mit braunen Läufen sind derzeit nicht erwünscht, um den Unterschied zu ähnlichen europäischen Sportrassen zu betonen.")

The first FCI breed standard, published 23rd November 1966, had almost identical wording:

"Grey and black-and-tan are not desired, to emphasize the difference to similar European sporting breeds."

It is important to note that when the Menzels wrote their early standard, the term "sporting breed" referred to dogs used for hunting and field sport, not merely the breeds belonging to the AKC Sporting Group.

It could be argued that the Menzels were referring to the grey seen in the Weimaraner, caused by dilution, a recessive mutation on the D locus. The FCI standard describes the grey of the Weimaraner as "silver, roe or mouse grey, as well as shades of these colours." However, it seems unlikely to confuse a Canaan Dog with a Weimaraner, so it is even more likely that the Menzels were referring to spitz-type breeds like the Norwegian Elkhound (Gråhund), Wolfspitz, or Laika-type hunting dogs, whose grey is caused by the agouti (aw) allele, often in combination with black tipping.

In the many genetic reports on Canaan Dogs that I have seen, I have yet to see any cases of dilution or agouti (aw) alleles.

Current research points to a different allele altogether that is behind "grey" Canaan Dogs: **Eg**, also called "grizzle" or "domino black," first found in Saluki, Afghan Hound, and Borzoi. Under certain circumstances, Eg can inhibit the production of black pigment (eumelanin) in a dog's coat. We have seen about 20 Canaan Dogs having been tested positive for Eg so far, and are continuing to support Laboklin (Germany) in their study on its effects and interaction with other genes.

What we have observed so far is that Eg is only expressed in Canaan Dogs that are **Kb/ky**. If they are Kb/ky and Eg/Eg, we seem to get stronger grey. Canaan Dogs that are Kb/ky and carry one Eg allele together with recessive red (Eg/e) tend to range from lighter grey to dark sandy tones.[10] Eg paired with wild-type E does not appear to produce visible grey.[11] These are hypotheses based on limited samples and not yet scientifically validated.

It is also important to note that **Eg may be invisible** in dogs that are **Kb/Kb**, **ky/ky**, or **e/e** (recessive red), which overrides almost everything else and produces red, yellow, apricot, cream, or lemon regardless of other loci. As a result, even Canaan Dogs that carry dominant black (Kb) will look red or cream if they are recessive red (e/e), because this switches off their skin cells' ability to produce black (eumelanin).[12] But they can still pass dominant black on to their puppies, as well as Eg, without us even being aware that it is there. Only a genetic test can tell us. Please beware that with some providers we have to buy a specific test for Eg, because it may not be included in their regular E locus panel.

Here are some examples of Canaan Dogs with Eg:

Canaan Dog with eg/e

[10] All these varieties can show white spotting depending on their S locus alleles, which does not appear to be suppressed by Eg.

[11] A 2024 study has proposed that Eg is recessive to wild-type E rather than dominant, as had earlier been assumed — which would explain why Eg paired with E produces no visible effect. This is a very recent finding, and general product-description pages across many testing providers have not yet been updated to state a position on it either way. Laboklin's own genotype reports for this test, however, already use notation consistent with the newer hierarchy. Honkanen, L., Loechel, R., Davison, S., Donner, J., & Anderson, H. (2024). Canine coat color E locus updates: Identification of a new MC1R variant causing 'sable' coat color in English Cocker Spaniels and a proposed update to the E locus dominance hierarchy. Animal Genetics, 55(2), 291–295. https://doi.org/10.1111/age.13398

[12] Please note that recessive red is not known to cause any health issues. What we often see connected to recessive red Canaan Dogs are noses with reduced black pigment, however.

Canaan Dog with eg/e (same dog, in different lighting conditions)

Canaan Dog with eg/eg

With regard to breeding, eliminating Eg carriers from the breeding pool would seem like an overreaction and would reduce genetic diversity. In conservation breeding, the priorities are:

1. Produce as many healthy puppies as possible.
2. Maintain or improve genetic diversity.
3. Consider cosmetic preferences only after these goals are met.

If we feel concerned about producing grey-ish puppies, we can test both parents for Eg specifically. The likelihood of grey offspring depends on the interaction of several loci, and our fellow breeders are welcome to seek assistance in interpreting results — but this should not override more important considerations.[13]

[13] It should be mentioned that in the Canaan Dog breed standard of the Royal Kennel Club (UK), "grey" is not marked as unacceptable, only as "undesirable."

INFOBOX 2: Why "Grey" in Canaan Dogs Is Not Dilution or Agouti

Not dilution (D locus)
- Weimaraner-type silver-grey
- No dilution alleles found in tested Canaan Dogs

Not agouti (aw allele)
- Wolf-grey/Agouti seen in Elkhounds and Laika types
- Not found in Canaan Dogs

Likely Eg (grizzle/domino)
- First identified in Saluki, Afghan Hound, Borzoi
- Expression depends on K locus, and seems to require e as the second E-locus allele — Eg paired with wild-type E does not seem to produce a visible effect
- Can produce shades from light grey to dark sandy

2.3 Conclusion

Coat colour genetics in the Canaan Dog are complex, and in many cases not yet fully understood. What matters most is that none of the colour variations currently observed — including asymmetrical masks, greyish coats, or recessive red — are known to be linked to health problems. Excluding dogs for cosmetic reasons would unnecessarily shrink an already critically small gene pool. For a breed with a low effective population size, every genetically healthy dog is valuable. Our priority must be to preserve genetic diversity, not to narrow the breed based on colour preferences or incomplete genetic information.

As research on breeding practices shows, the long-term genetic health of the Canaan Dog is shaped by its historical founder base, but its future depends almost entirely on how we breed today.[14]

[14] cf. 1 and "Recommended Further Reading" at the end of this paper

Practical Recommendations for Managing and Expanding Genetic Diversity

- **Keep litter gCOI below the breed average:** aim for ~10% in the short term and gradually move down towards 5%.
- **Aim to limit stud use:** no male should sire more than 5% of puppies born globally within any five-year window. This helps prevent "popular sire effect," the most common cause of genetic diversity loss in purebred dogs.
- **Use females as evenly as possible:** females in a kennel should have roughly equal numbers of litters and produce no more than 5% of Canaan Dog puppies born globally within any five-year window,
- **Exchange 2–3 stud dogs** per year between the subpopulations.
- **Use frozen semen:** freeze semen from stud dogs and exchange internationally.
- **Rely on genomic tools:** Embark, MyDogDNA and similar platforms provide more accurate diversity metrics than pedigree-based estimates.
- **Prioritise genetically rare individuals:** Canaan Dogs with uncommon haplotypes, low gCOIs and low kinship are especially valuable.
- **Develop a breed-wide kinship matrix:** shared MK (mean kinship) data for the Canaan Dog would support diversity-focused breeding decisions, because it reflects true genomic similarity and is more informative than pedigree COI.
- **Aim for low-kinship pairings:** using MK data, we could try to avoid high-kinship pairings and aim for low-kinship breeding.
- **Use regional outcrossing within the breed:** US x Europe x Israel pairings increase heterozygosity and reduce mean kinship.
- **No exclusion for cosmetic traits:** asymmetrical masks and grey-ish coats in the Canaan Dog have no known health relevance and no validated genetic basis.
- **Test colour genes only when needed:** Eg and other loci can be invisible in many genotypes; testing can be used for planning but should not override diversity goals.
- **Prioritise health and genetic diversity over aesthetics:** in a critically small breed such as the Canaan Dog, cosmetic preferences should never motivate exclusion.

3. Challenge #3: Managing health issues

Having examined the structural vulnerabilities of the Canaan Dog population (Challenge #1) and the urgent need to preserve and expand genetic diversity (Challenge #2), we now turn to a closely related issue: the management of hereditary health risks in a critically small breed. Health cannot be considered in isolation. In a population with low effective size, every health decision has consequences for genetic diversity and every restriction on diversity affects long-term health. The following sections outline the major health considerations for the Canaan Dog from my view as well as the complexities introduced by both limited population size and modern genetic testing.

3.1 General vulnerability of small populations

Health management in a critically small breed requires a balance between caution and practicality. Not every mutation is equally relevant, not every test is reliable, and not every risk can be eliminated without harming genetic diversity. At the same time, breeders carry an ethical responsibility to prevent any avoidable suffering and to ensure that breeding decisions support the long-term viability of the breed.

Small populations are inherently more vulnerable to hereditary disease. Conditions such as hip dysplasia, elbow dysplasia and hereditary eye diseases occur not only in genetically bottlenecked pedigree breeds but also in indigenous dog populations without formal health checks. A specialist in Germany, for example, recently evaluated hip X-rays from a large number of herding dogs being considered for FCI recognition; most received only C or D ratings. This illustrates that some health issues arise regardless of formal breeding systems.

Other conditions may appear only once genetic tests become available, provided those tests are reliable. Some diseases emerge through inbreeding; others may be introduced through crossbreeding or through founder dogs with unknown genetic backgrounds. Understanding these dynamics is essential for responsible health management.

3.2 Degenerative Myelopathy (DM) as the most relevant known hereditary disease

Most will agree that in the Canaan Dog, the most pressing genetic health concern at this point is Degenerative Myelopathy (DM). To our current knowledge, DM appears to affect dogs that are homozygous for the SOD1 mutation — though not necessarily all of them, as penetrance is not fully understood even in breeds where DM is well established. What is clear is that DM is a serious, late-onset neurodegenerative condition, and that breeders in a critically small population must manage it with both scientific accuracy and conservation awareness.

Opinions on how to incorporate DM testing into breeding programs vary widely, ranging from excluding all carriers to questioning the relevance of the test altogether. One article published by a large national kennel club argued against using DM testing in breeding decisions, citing uncertainties such as complex inheritance, unclear causes of DM-like symptoms, and the lack of breed-specific clinical evidence. This last point deserves careful examination, because it is sometimes misapplied in discussions about the Canaan Dog — and because the absence of breed-specific pathology does not imply the absence of disease, nor does it invalidate the substantial body of evidence from other breeds. Absence of confirmation is not confirmation of absence.

Given the importance of clarity, and the need for breeders to rely on accurate, authoritative information, I contacted the Canine Genetics Laboratory at the University of Missouri and Dr. Joan R. Coates, DVM, MS, DACVIM (Neurology), whose team is the leading research group on DM. The following statement was provided by Dr. Coates and the Canine Genetics Laboratory, and is quoted here verbatim to ensure precision and correct attribution.

> "Degenerative Myelopathy (DM) is widely observed and diagnosed across many breeds and mixed breed dogs. The SOD1 mutation identified as responsible for development of DM by the research team at the University of Missouri-Columbia College of Veterinary Medicine (MU CVM) has been identified in over 200 breeds, and in mixed breed dogs. The Canaan Dog is among these breeds, and there are genetically “at risk” dogs reported with the classic clinical signs of progressive loss of sensation and muscle wasting, beginning at about 7-10 years of age with dragging toes in the hind limbs, progressing to muscle loss and loss of function in the rear legs and eventually in the front limbs, and eventually spreading to the lungs and brain. This slow but continual deterioration from first scuffing toes to severe enough loss of function that quality of life is poor and dogs are euthanized is generally 6-18 months.

A presumptive diagnosis of DM is generally made based on clinical signs, age of onset, and progression of loss of function over time. A DNA test result showing the dog is homozygous for the SOD1 mutation and genetically "at risk" adds to that presumptive diagnosis. Definitive confirmation of DM is via post-mortem examination of a section of spinal cord, and histopathologic confirmation of cellular changes that are the hallmarks of DM. The UMC CVM research team, led by Dr Joan Coates, has made this histopathologic confirmation of DM in over 40 breeds and some mixed breed dogs. Making this confirmation in additional breeds is dependent on owners of clinically diagnosed dogs going thru the extra steps of having spinal cord samples collected and sent in for histopathology at a time when they've been thru a year or more of watching their dog deteriorate, and are saying an emotional goodbye – so unless arrangements have been made well ahead of time, and the veterinarian is prepared to collect the sample, this step is frequently not made.

The Canine Genetics Lab (CGL) at MU CVM has DNA tested 427 Canaan Dogs as of July 1, 2026. Of these, 226 tested NORMAL, 170 tested CARRIER, and 31 tested AFFECTED/AT RISK. This is an allele frequency of 27%. This is probably skewed a bit higher than the overall population of Canaan Dogs, as the dogs tested are not random, but are dogs that their owners chose to test. Often the motivation for seeking the DNA test is clinical signs suggestive of DM, or dogs are from a family with a history of DM diagnosis, and these are more likely to test carrier or at risk. The CGL does not have access to statistics from the many other labs around the world, and major testing companies like Embark and Wisdom also offering this test, which could potentially give better insight into the true frequency of this mutation.

Dr Coates has received a post-mortem spinal cord sample from only one Canaan Dog, and the histopathological findings were inconclusive. To be able to say anything more definite about DM in Canaan Dogs, the research team needs additional spinal cord samples from this breed. Ideally, the dogs suspected of having DM should have a thorough clinical workup when initially diagnosed and be followed through the disease progression by a neurologist, so that clinical status is well documented. Arrangements for collection and shipping of postmortem samples should be made in advance of need, so everything is in place when the final day comes.

The research team at MU CVM is also investigating similar degenerative diseases that look like DM but may be a different issue. In English Cocker Spaniels; there is a late onset disease that is like DM, but affects all 4 limbs, and progresses more slowly. The mutation for this is known. There may be mutations in other genes that act as modifiers, protecting the dog from showing clinical signs of DM until later than is typical, or allowing the disease process to be expressed differently. There also may be other, likely rare, mutations causing slightly different forms of DM, just as there are many genes and many mutations associated with ALS in humans. There is active research at MU CVM to answer these additional questions. It is possible that Canaan Dogs have a similar condition that mimics DM but is a different form of neurodegeneration. It's also possible that there is clinical DM as seen in other breeds, as well as a second, mimicking condition that has not been defined. To investigate and begin to understand this, the researchers need DNA samples, postmortem tissue samples, and information from well-documented cases in Canaan Dogs. Owners of dogs with suspected DM, or similar

neurodegenerative issues, are encouraged to contact the MU CVM researchers at MUCVMk9genetics@missouri.edu, or Dr. Coates (coatesj@missouri.edu).

While additional research is in progress, and DM cases are in the process of being better defined in this breed, what should concerned Canaan Dog breeders do? Published research demonstrates a strong correlation between dogs that are homozygous for the SOD1 mutation and dogs that eventually develop clinical DM. Even if there are Canaan Dogs that are apparently resistant to developing disease in spite of an "at risk" genetic profile, until that is better understood, it is wise to use DNA testing to understand the genetic status of dogs being considered for breeding, and to make informed choices for matings that reduce risk in the next generation. Carrier status is not zero risk, but the risk of developing clinical DM is extremely small and has not been reported in most breeds. Dogs that are genetically normal for the SOD1 mutation are essentially not at risk. By having at least one parent DNA-tested NORMAL, breeders can reduce risk in new generations. Otherwise, outstanding dogs that test CARRIER, or even AT RISK can be included in a carefully planned breeding program to preserve their many other positive traits and genetic diversity, while also reducing DM risk in the next generation. DNA testing completed to this point show that the majority of Canaan Dogs are testing NORMAL, so there should be many appropriate choices for mates when breeding a carrier or at-risk dog. The DM DNA result should not be the only feature considered when making breeding choices – breed the whole dog, not just a single test result. With time and careful choices being made, positive traits and genetic diversity can be preserved while also decreasing risk of clinical DM. Even without a complete understanding of why some genetically at-risk Canaan Dogs develop clinical disease and some do not, breeders can reduce the risk of facing the possibility of disease by using the tools and knowledge currently available."

While pairing AT RISK (A/A) dogs and NORMAL (N/N) dogs is genetically sound as a way to avoid producing affected puppies — every A/A × N/N litter is 100% carriers (N/A), with no A/A puppies possible — that also means concentrating the mutant allele into every single offspring, rather than roughly half as a carrier-to-clear pairing would. In the Canaan Dog's current breeding culture, even a single copy of the mutation makes a puppy very difficult to place; a litter that is entirely carriers is not, in practice, a realistic outcome for most breeders to plan around. Given this, and the added concentration of the mutant allele in the population, I would not recommend breeding an AT RISK dog at this time, however outstanding its other qualities.

Weighing the evidence as a whole, the most reasonable and proportionate approach is to test for DM and to avoid producing homozygous (A/A) offspring — not by excluding carriers from breeding, which in a small population would cause significant genetic harm, but by ensuring that carriers are only mated with clear dogs. This strategy balances immediate risk reduction with long-term conservation of diversity, and it is increasingly adopted by breeders, required by several kennel and breed clubs, and supported by the available evidence on SOD1-associated DM.

3.3 Introducing wild-caught founders

The introduction of dogs from the wild through *miyun*[15] is one of the few tools available to expand the genetic base of the Canaan Dog. However, it also introduces uncertainty. Even when a dog passes *miyun* based on phenotype and temperament, its ancestry and genetic background remain largely unknown.

In a breed with ongoing *miyun*, the assumption that *'the breed is free of X'* cannot automatically be applied to every founder line. Testing only for disorders already documented in the Canaan Dog risks missing variants that are novel to the breed and could impact the health of affected dogs. To mitigate this risk, every wild-caught dog should be treated as a genetic unknown until sufficient evidence accumulates. This requires:

- comprehensive health screening
- repeated observation over time
- targeted genetic testing interpreted with veterinary and scientific support.

Equally important is the controlled, stepwise integration of such dogs into the breeding population, as is the current practice: beginning with limited, carefully selected matings, monitoring the resulting offspring, and avoiding the rapid spread of any new founder line until its health profile is better understood. In a critically small breed, this measured, evidence-based approach allows us to benefit from the genetic diversity that *miyun* provides while minimising the risk of inadvertently introducing hereditary disease.

3.4 Limitations of modern genetic testing

Modern canine genetic testing is a powerful tool, but it must be interpreted with caution. Unlike human medical genetics, canine testing is not subject to strict regulatory oversight. There are no EU- or US-wide standards governing test development, validation or accuracy. The market is large, commercially driven and largely unregulated.

Key limitations include:

- lack of transparency about testing methods and algorithms
- tests released without peer-reviewed evidence
- markers identified in one breed being applied to others without validation
- reliance on proprietary data that cannot be independently verified.[16]

As a result, many tests detect genetic variants whose clinical relevance in the Canaan Dog is unknown. This does not mean such tests are useless — but it does mean they must be interpreted carefully and never used as the sole basis for excluding a dog from breeding.

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[15] *Miyun* is the controlled evaluation used by the Israel Kennel Club to determine whether a free-living Canaan Dog may be accepted as a founder: specially authorised judges assess the dog's phenotype, movement and behaviour against the traditional desert-bred type and verify its origin; if approved, the dog is entered into the studbook appendix, receiving an APX number, and only its descendants can later obtain full registration once they form a three-generation pedigree under FCI rules.

[16] See recommended further reading at the end of this article.

3.5 Examples of uncertain or conflicting test results

Several examples illustrate the challenges of interpreting genetic test results in the Canaan Dog.

3.5.1 Copper Toxicosis (Accumulating)

Some laboratories, including Embark, report variants associated with copper toxicosis. However, Embark explicitly states that:

- the variant has not been validated in the Canaan Dog
- its clinical relevance is unknown
- research is ongoing
- breeders should simply monitor results.[17]

To our knowledge, there is no clinical evidence yet of copper toxicosis in the Canaan Dog. Such results may confuse puppy buyers and should be interpreted with caution.

3.5.2 Intervertebral Disc Disease (IVDD)

Embark's linkage test has identified some Canaan Dogs as carriers or at risk for IVDD. However, retesting the same dogs with Laboklin's mutation test showed them to be clear. This discrepancy highlights the limitations of linkage tests, which examine DNA sequences near a mutation rather than the mutation itself. Even if the linkage test were accurate, we still lack clinical evidence that IVDD occurs in the Canaan Dog.

These examples underscore the need for careful interpretation and expert consultation.

[17] The actual report will read like this: "X is not known to be at increased risk for Copper Toxicosis (Accumulating). (…) We do not know whether this increases the risk that X will develop Copper Toxicosis (Accumulating). (…) Research studies for this variant have been based on dogs of other breeds. Not enough dogs with X's breed have been studied to know whether or not this variant will increase X's risk of developing this disease. (…) Research into the clinical impact of this variant is ongoing. We recommend tracking this genetic result and incidence of Copper Toxicosis (Accumulating) in your breeding program and related dogs."

Reliability of Genetic Testing Categories

Testing Category	Reliability Level	What It Actually Tells You	Main Limitations / Risks	Examples
Mutation tests	**Moderate to high** (when mutation is known + validated)	Detects the *actual* causal mutation; best available when clinically confirmed in the breed.	Only reliable if the mutation is proven relevant in Canaan Dogs; some mutation tests are released without peer-reviewed evidence.	Laboklin's mutation test for IVDD contradicted Embark's linkage test.
Linkage tests	**Low to moderate**	Detects DNA markers *near* a mutation; can indicate risk haplotypes.	Indirect; can misidentify carriers; accuracy varies by breed; may not detect the true mutation.	Embark's linkage test flagged IVDD "carriers" that mutation testing showed as clear.
Tests validated only in other breeds	**Low**	Shows variants known in other breeds; may be useful for long-term monitoring.	No evidence they cause disease in Canaan Dogs; can confuse owners; may lead to unnecessary exclusions.	Copper Toxicosis variant: Embark explicitly states relevance to Canaan Dogs is unknown.
Tests with no clinical evidence in Canaan Dogs	**Very low**	Indicates a genetic variant exists.	No proof it causes disease; may be meaningless; can create false alarms; should not guide breeding decisions alone.	Many panel tests fall here; IVDD and Copper Toxicosis are highlighted as lacking clinical evidence in the Canaan Dog.

Degenerative Myelopathy (DM) is currently the *only* hereditary disease with strong clinical suspicion in the Canaan Dog. All other tests — whether linkage, mutation, or panel-based — lack breed-specific clinical evidence and should be interpreted with caution.

3.6 Conclusion

Managing health in the Canaan Dog requires navigating a delicate balance between two equally important responsibilities: preventing avoidable suffering and safeguarding the genetic diversity on which the breed's long-term survival depends. In a population with a critically low effective size, these goals are inseparable. Excessive caution can shrink the gene pool; insufficient caution can allow hereditary disease to spread. The task before us is therefore not to eliminate all risk — an impossible standard — but to manage risk intelligently, proportionately, and with scientific discipline. Until genetic tests become more reliable and breed-validated, results — particularly those indicating homozygosity for a mutation — should always be interpreted in consultation with veterinary and scientific advisors. Our long-term responsibility is to preserve the breed's genetic diversity while minimising health risks, and achieving this balance demands careful, case-by-case evaluation rather than rigid rules or blanket exclusions.

Degenerative Myelopathy remains the only hereditary disease for which we currently have strong clinical evidence in the Canaan Dog, and avoiding the production of affected dogs is both feasible and ethically necessary. Beyond DM, however, the landscape becomes more complex. The introduction of wild-caught founders through miyun is essential for expanding genetic diversity, yet it also brings unknowns that cannot be resolved through genetic testing alone. Likewise, the rapidly growing market for canine genetic tests offers valuable tools but also produces results whose relevance to our breed is uncertain, unvalidated, or contradictory.

In this environment, responsible health management depends on three principles:

- evidence-based interpretation, grounded in veterinary and scientific expertise
- measured, stepwise decision-making, especially when integrating new founder lines
- a commitment to preserving every genetically healthy dog, unless there is compelling evidence to do otherwise.

By applying these principles consistently, we can protect the welfare of individual dogs while maintaining the genetic resilience the breed urgently needs. The future of the Canaan Dog will depend not on eliminating all possible risks, but on managing them wisely — guided by science, informed by experience, and always mindful of the breed's genetic foundation.

Practical Recommendations for Managing Health in a Small Population

- **Prioritise evidence-based health management:** focus on conditions with strong clinical relevance in the Canaan Dog; avoid overreacting to unvalidated risks.
- **Use DM testing proportionately:** prevent producing homozygous-affected puppies, but do not exclude carriers; maintain genetic diversity while preventing avoidable suffering.
- **Interpret genetic tests with caution:** many variants lack validation in the Canaan Dog breed; treat uncertain results as informational, not exclusionary.
- **Avoid removing dogs based on unvalidated markers:** linkage tests, breed-unspecific variants, and low-evidence findings should never drive breeding restrictions.
- **Integrate wild-caught founders stepwise:** treat new founders as genetic unknowns; use limited initial matings, monitor offspring, and expand use based on accumulating evidence.
- **Balance health and diversity:** in a critically small breed like the Canaan Dog, eliminating lines for minor or uncertain risks can cause more long-term harm than benefit.
- **Use veterinary and scientific consultation:** complex or conflicting test results should be interpreted with expert support rather than in isolation.
- **Document and share health outcomes:** transparent reporting of clinical cases, test results, and line-specific observations strengthen breed-wide decision-making.
- **Avoid health-based over-selection:** selecting only the healthiest-tested dogs will narrow the gene pool; we should aim for broad and balanced use of healthy individuals.
- **Monitor, not panic:** track emerging issues, but avoid premature conclusions; small populations require patience and long-term observation.

4. Challenge #4: When Buyers Are Few, Placement Becomes Conservation

In a breed with a critically low effective population size, its long-term future depends not only on breeders and their mating decisions but also on the next generation of owners. Every puppy, in theory at least, represents an important proportion of the future breeding population. This makes the identification of suitable puppy buyers a conservation issue rather than a purely practical one. The challenge is not simply to find good homes, but to find homes that can support the breed's effective population size, genetic diversity, and long-term viability.

In numerically large breeds, most puppies will never contribute genetically to the population, and this has little impact on long-term diversity. In the Canaan Dog, the situation is fundamentally different. A puppy placed in a home that is unwilling or unable to keep breeding options open represents a lost opportunity for the breed. Conversely, a puppy placed in a home that is open to future breeding, committed to health testing, and willing to collaborate with breeders can meaningfully increase the breed's genetic security.

This means that puppy placement is ideally approached with the same strategic thinking as mate selection or founder management.

4.1 Falling demand and the power of perception

It is being reported by breeders worldwide that applications to buy a Canaan Dog puppy have dwindled. In some countries, including Germany, dog breeders in general are struggling to place puppies, especially in breeds perceived as "demanding". It sometimes feels as if many prospective owners are looking for a dog that is self-training, self-cleaning, and easy to "store" when they go on holiday.

There are, of course, serious and valid reasons why demand for Canaan Dogs is not high: economic uncertainty, political instability, the Covid-era puppy boom and its aftermath, the influx of "rescues" from Eastern Europe and the Middle East, exploding veterinary costs, rising expenses for breeders leading to higher puppy prices, and animal-rights campaigns against breeding or even keeping pets. On top of that, spitz-type dogs are generally a harder "sell" because they bark more and have a mind of their own, and the Canaan Dog is often perceived as being at the sharper end of that spectrum. In Germany, very few people in the dog world have ever heard of the breed, and some judges remain wary because they were snapped at by Canaans a decade or more ago.

Almost everyone else has no idea the Canaan Dog exists. People who contact us about a puppy — apart from those who already have a "Canaan Dog" from a shelter and are asking for help — usually fall into one of three groups:

- They had a Canaan Dog before and are now considering another.
- They discovered the breed online or in a dog-breed book.
- They used an online "Find your breed" tool and got "Canaan Dog" as a match, often based on criteria like medium size, health, alertness, and independence.

We have always been a bit worried about what they might find on the internet, because some sources describe the Canaan Dog's temperament as problematic and hard to handle. With the rise of AI-driven search engines, our concern had grown.

4.2 What AI says about the Canaan Dog

Curious and slightly apprehensive about what potential puppy buyers might see, I asked Microsoft's Bing.com (which combines OpenAI's GPT-4 with Bing search results) "What are Canaan Dogs known for?" The answer, condensed, was:

- Ancient origins – one of the oldest surviving dog types, descending from Middle Eastern pariah dogs.
- Exceptional watchdog instincts – naturally wary of strangers, extremely alert, quick to react, guarding without unnecessary aggression.
- High intelligence and independence – quick learners, problem-solvers, but self-reliant and sometimes stubborn.
- Strong loyalty – deeply devoted to their family, reserved with outsiders.
- Adaptation to harsh climates and versatility – robust, desert-adapted dogs historically used for herding, guarding, and military work.

The "temperament snapshot" emphasised: alert and watchful, loyal to family, reserved with strangers, independent thinkers, highly trainable with the right handler, energetic and needing mental stimulation.

This is, in many ways, a fair summary. It does not portray the Canaan Dog as a monster, but it clearly signals that this is not an easy-going, universally sociable pet. For preservation, that nuance is crucial: we need buyers who are attracted to these traits for the right reasons and who understand what they imply in daily life.

Because the word "primitive" appears frequently in AI-generated descriptions, I also asked Bing what "primitive" means in this context. The answer, again shortened, was:

- Strong survival instincts – thinking for themselves, assessing danger, reacting quickly.
- High environmental sensitivity – noticing sounds, movement, and changes.
- Natural wariness of strangers – evaluating people before engaging.
- Independent decision-making – not blindly following commands.
- Low tolerance for chaos – easily stressed by noise and unpredictability.
- Strong territorial instincts – natural guarding of their space.

Importantly, Bing also clarified that "primitive" does not mean inherently aggressive, untrainable, or "wild" in a dangerous sense. Primitive dogs are often very smart, but they think like problem-solvers, not like obedient working breeds.

From a conservation perspective, this is actually helpful: it frames the Canaan Dog as a sensitive, thinking dog that needs early socialisation, clear boundaries, respect for its sensitivity and predictable routines. Owners who can provide that are exactly the kind of long-term partners the breed needs.

Google's Gemini paints a similar picture, perhaps a bit more demanding in tone: independent and protective guardians; highly intelligent and trainable with firm, consistent, reward-based methods; extremely vocal; versatile working dogs; and hardy, adaptable, typically healthy. "Extremely vocal" may scare off some potential buyers — but that may not be entirely negative if it filters out people who would struggle with a naturally alert watchdog.

4.3 Aggression, reputation, and the wrong kind of fascination

To probe further, I asked Google's AI whether the Canaan Dog is known as aggressive. Interestingly, results varied depending on the day I was asking, but the general takeaway was this: Canaan Dogs are not naturally aggressive towards humans, but they *are* highly territorial and typically reserved or "suspicious" of strangers. Their natural instinct is to back away from a stranger rather than attack, but within their own territory, they may put on a "big show" of barking and snarling to deter intruders, preferring to stay out of reach rather than engage physically. However, dog-on-dog aggression, especially toward same-sex or unfamiliar dogs entering their space, is possible.

On my first attempt, the first source Google cited for its answer was "101 Reasons For Not Choosing A Canaan Dog" by Dr Victor Kaftal, a very detailed portrayal of Canaan Dog behaviour many of us know. Most European puppy buyers will never see it; instead, they will encounter AI summaries, breeder websites, and kennel club pages. As we have seen, this information does not necessarily deter them. In fact, it may have the opposite effect: the breed sounds rare, ancient, intelligent, "primitive" and perhaps slightly dangerous — all rather fascinating to the wrong kind of person.

The recommended management strategies, such as extensive socialisation, consistent training, and a suitable environment, are all things responsible breeders already emphasise. The problem is not that these descriptions are wrong; it is that they can easily be misunderstood or selectively interpreted.

Many potential puppy buyers are attracted to the Canaan Dog's appearance and independence, but also by its sometimes romanticised perception as one of the last "natural", even "wild" dogs, but are unprepared for the realities of living with a dog that retains strong natural instincts. When we first saw Canaan Dogs in a live Crufts broadcast, commentator Frank Kane described them as "really a feral dog" or, more precisely in later years, as having "its origins in the feral dog of the Middle East." We were fascinated by their shape and movement, but also by their origin story and temperament. Because we already had a German Spitz from old lines, we knew something about living with an alert, independent dog that sometimes seems to be too clever for his own good. When we met our first Canaans in person, we were even reminded of wolves. Indeed, a personal friend who shares his private forest with wild wolves once described our Lucy as "the most wolfish dog I've ever met" — but purely because of her natural alertness and wariness, not because of aggression or any "Game of Thrones" fantasy.

Dogs are not wolves, and Canaan Dogs are not "wild dogs," even if they are sometimes described that way. Associating the breed with wildness or wolf-likeness is harmful in two directions: it can either scare off suitable homes or attract people who want a rare, "special" dog with a semi-wild aura without understanding what it means to live with and train such a dog. As Bing rightly put it: the Canaan Dog is "highly trainable… with the right handler." That last part should be non-negotiable.

From a preservation standpoint, this matters deeply. A single Canaan Dog placed with someone who wants a status symbol, a "wolf-like" pet, or a challenge for their ego can do more damage to the breed's reputation than several well-placed dogs can repair.

Therefore, selecting buyers who understand the breed's temperament and behaviour is essential for long-term conservation. Poor placements can lead to behavioural issues, rehoming, early neutering, all of which reduce the dog's potential contribution to the breed. Canaan Dogs in the wrong hands are also the cause of stories that make trainers, judges, and even the general public wary of the breed. That, in turn, reduces demand, shrinks the pool of potential responsible owners and thus limits our ability to maintain a viable breeding population.

In our experience, it is vital to point out to potential puppy buyers that the Canaan Dog is not necessarily an easy-going or cuddly dog — while they can at least be the latter —, but also to underline their adaptability and resilience. Furthermore, instead of simply looking for *more* puppy buyers, we should look for the *right ones*: people who might be attracted to the Canaan Dog because they love working with this type of dog, because they share an interest in the breed's history, are fascinated by their origin story, have a connection with the region and culture they come from, etc. In trying to raise awareness of the Canaan Dog, these are the target audience.

4.4 Who Canaan Dogs are not for — and who they are for

In our view, portraying the Canaan Dog as wild or wolf-like is just as detrimental as portraying it as an easy-to-train, low-maintenance family pet. The Canaan Dog, like many other breeds, is not for everyone. The right people for our puppies are not those looking for an ego boost, but those willing to put in consistent work, to find a good trainer (and be ready to try another one), and to reflect honestly on their own behaviour and training methodology.

It is sometimes said that Canaan Dogs should only go to people who have owned dogs before. Our experience is more nuanced: first-time dog owners who meet all our other criteria can be more open to our guidance, and to that of their trainers, than people who have owned other breeds and believe they already know everything. What matters is not the number of dogs someone has owned, but their willingness to learn, to respect the Canaan Dog's nature, and to commit to our puppies for the long term.

This is again critical from a conservation perspective. The "right" puppy buyers are not just good pet homes, they are potential future collaborators: owners who keep in touch, share health and behaviour information, participate in health testing, and may one day contribute to breeding. Every such home keeps a genetically valuable dog available to our breed. Every unsuitable home risks losing that dog to behavioural fallout, early neutering, rehoming, shelters, or worse — and with it, a piece of the already small genetic puzzle.

4.5 How people actually find us

We fully recognise how demanding it can be to place a Canaan Dog puppy. The first challenge is visibility: how do people find us when 99.99% of them have never heard of the breed?

Advertising puppies on general online platforms has rarely been worth the effort for us; there are simply too many dogs competing for attention. The German kennel club (VDH) and our breed club both provide information about the Canaan Dog and links to our kennel on their websites, but people have to know what they are looking for to find it.

Some of our puppy buyers discover the breed through online questionnaires or smartphone apps like PupMatch or Pawsonality. Others find it in books, or — here in Germany — through a TV report on our Luca's litter with Gabi Viol's Alija, recorded in 2023 for a popular pet show and still repeated occasionally. Interest that comes through these channels is generally by people who are not just curious but willing to learn more, which is a good starting point.

4.6 Our placement strategy: building a preservation-minded community

Once interest is there, what has worked best for us is to invite prospective buyers into our home so they can meet our dogs — ideally before a litter is even planned. We also offer to connect them

with existing puppy owners, who are usually happy to share their experiences. This gives potential buyers a realistic picture of daily life with a Canaan Dog and gives us a sense of how they respond to that reality.

Our goal is to have at least three to four solid candidates before the litter is born. Once the puppies are there, we can observe their individual temperaments and consider which puppy might be a good fit for which home. If things do not feel right, we prefer to be patient (or stubborn) rather than place a puppy with someone we are not 100% sure about.

If they buy one of our puppies, they are not joining a church, but they do become part of our Canaan Dog family. As a famous Klingon once said, "Trust is earned, not given away." Only a few Canaan Dogs ending up in the wrong hands can be more detrimental to the breed's survival than a breeder having to wait weeks or even months to find the right home. Good puppy placement not only secures happiness for our individual puppies, it also creates a feedback loop that benefits the breed: owners who feel supported are more likely to stay in touch, to share health and longevity data, to participate in genetic testing, and to consider keeping dogs intact under guidance.

Over time, this builds a network of homes that function as a living infrastructure for the breed's genetic management and its public image. Because the Canaan Dog is rare, every owner becomes an ambassador, just like a well-socialised puppy. Owners should be encouraged to represent the breed accurately, avoiding both exaggeration and romanticization. Balanced, honest communication helps ensure that future owners are well-prepared and committed.

For a critically small breed, careful placement is not a luxury; it is a conservation measure. When every puppy is precious, every buyer must be too.

4.7 Keeping breeding options open

In many popular breeds, puppies are routinely sold on non-breeding contracts. For the Canaan Dog, this approach risks being counterproductive. While not every dog should be bred, every dog should retain the option until adulthood. Many traits relevant to breeding suitability — temperament, health, structure, and overall stability — cannot be reliably assessed during puppyhood.

To preserve the possibility of future breeding decisions, our puppy contracts include a clause requiring that no dog be neutered without our written consent and never before two years of age. This does not obligate the owner to breed, nor does it require the breeder to use every dog. It simply preserves options in a breed that cannot afford to lose them prematurely.

A second clause addresses long-term stewardship rather than reproduction: we retain a first right of refusal to repurchase the dog should the buyer be unable or unwilling to keep it. The owner is legally required to offer the dog back to us before transferring ownership to any third party. This safeguard prevents uncontrolled rehoming and ensures that dogs remain within a responsible, conservation-minded environment throughout their lives.

A conservation-minded approach therefore requires flexibility. Puppies should be placed in homes that are open to keeping the dog intact, willing to complete health testing, and prepared to collaborate with breeders on future decisions. This does not obligate the owner to breed, but it preserves the possibility.

4.8 International cooperation and the global population

Finally, we would like to encourage breeders in Europe, Israel, the United Kingdom, and the United States to continue — and, if possible, expand — the exchange of puppies. Our aim should be to continue to work towards a single global population of Canaan Dogs rather than two largely separate subpopulations.

This is essential from the perspective of effective population size. A small breed split into regional subpopulations behaves genetically like several even smaller breeds. By placing puppies across borders in carefully chosen homes, we not only strengthen the social and practical network of the breed, but also create future opportunities for exchanging breeding animals. The "right" puppy buyers on one side of the Atlantic may one day become the key to introducing a much-needed bloodline on the other side. Placement becomes conservation.

In this sense, finding the right puppy buyers is about more than individual welfare or avoiding returns. It is about building a stable, informed, and cooperative human community around the Canaan Dog — one that can sustain the breed genetically, ethically, and practically into the future.

4.9 Conclusion

In a breed as small as the Canaan Dog, placement has always been about more than just finding good homes for our puppies, it has always been a conservation tool. Now, with public demand declining and online representation potentially misleading, we must actively shape perception and ensure that puppies go to owners who truly understand Canaan Dog behaviour. Clear communication about who the breed suits, and who it does not, helps prevent mismatches while attracting the right kind of interest, thus creating opportunity for future collaboration and the recruitment of new breeders.

Because most people discover the Canaan Dog through personal connections rather than broad visibility, they are usually open to learn more about the breed and stay in touch. Thoughtful placement keeps future breeding options open, strengthens cooperation across regions, and supports building a preservation-minded community. When buyers are few, every well-placed puppy becomes an investment in the breed's long-term survival.

Practical Recommendations for Placement and Conservation

- **Treat every puppy as a conservation asset:** in a critically small breed like the Canaan Dog, each well-placed puppy strengthens the long-term breeding base.
- **Prioritise committed, breed-appropriate homes:** find owners who understand the Canaan Dog's needs and are willing to support our long-term goals, especially by keeping their dogs available for breeding.
- **Maintain long-term contact with puppy owners:** regular communication and meetings ensure information flow, learning about the breed, health updates, and help keeping breeding options open.
- **Educate owners about the vulnerability of the breed:** transparency about the Canaan Dog's conservation status can foster understanding and willingness to participate in responsible breeding.
- **Support owners in keeping their dogs intact:** discourage neutering, or at least encourage delayed neutering, and provide guidance (e.g. on training) so more Canaans remain available for breeding evaluation.
- **Use contracts that preserve future options:** agreements should protect our puppies' welfare while allowing potential breeding if the dog matures well.
- **Place puppies internationally:** cross-Atlantic placements strengthen gene flow between subpopulations.

5. Challenge #5: Recruiting and Supporting New Breeders

5.1 Why new breeders are essential

All of the above remains abstract theory if we fail to encourage younger generations to start breeding the Canaan Dog. The breed cannot survive without new breeders entering the community. In a critically small breed, the number of committed, ethical breeders is often a more limiting factor than the number of dogs themselves. Without people willing to take on the responsibility of breeding, even the best dogs cannot contribute to the next generation.

However, becoming a breeder is a significant commitment, and many potential candidates hesitate due to lack of mentorship, uncertainty about health testing, or unfamiliarity with kennel club procedures. Experienced breeders therefore play a crucial role in lowering these barriers. Only a small proportion of puppy owners will ever be suitable breeders, and that is entirely normal; the goal is not to turn every owner into a breeder, but to identify and support those who have both the interest and the aptitude.

To ensure the success and sustainability of our efforts, the focus should again be on quality, not quantity. We are looking for people who not only understand and love their Canaan Dog(s), but who genuinely wish to contribute to the breed's preservation without seeking personal gain. This will typically involve:

- having more than one litter
- investing substantial amounts of energy, time, and funds; repeatedly
- cooperating with other breeders, ideally on both sides of the Atlantic
- joining a breed/kennel club within the AKC/FCI/RKC alliance, which recognise each other's pedigrees, and abiding by their rules and regulations
- health testing their dogs
- helping to improve the genetic diversity of the breed
- breeding Canaan Dogs according to the AKC, FCI, or RKC standards, and refraining from reproducing dogs with known health or temperament issues
- socialising their puppies extensively to ensure a smooth transition to modern family or farm living
- providing support to their puppy owners throughout the dog's lifetime
- committing to help rehome a dog from their breeding if problems arise, and ideally taking the dog back if no quick solution can be found, to prevent any Canaan Dog from ending up in a shelter

Given this list of challenges, it is particularly important — at least in Germany, and likely elsewhere — that we as more experienced breeders make ourselves available as mentors, because our breed club cannot offer that form of support. Experience internationally has shown that breeder-to-breeder mentoring is one of the most effective ways to recruit new breeders and thus help secure the breed's future.

5.2 Mentoring future breeders

Typically, the process begins when we as breeders encourage puppy owners to consider making their dogs available for breeding, provided their Canaan Dogs are healthy, of sound build and temperament, and do not display extremes in either. From the start, we invite potential puppy owners to visit the litter several times and follow its development, including through extensive video coverage, so that by the time they pick up their puppy, they have some idea of what it means to raise a litter.

Later on, meet-ups with our puppy owners are excellent opportunities to keep in touch and to train their eyes, helping them learn to assess their dogs in terms of structure, movement, and temperament. Where available, dog shows also offer valuable learning opportunities.[18]

Providing information on the first steps towards becoming a breeder is usually a longer process over several in-depth conversations. These discussions cover the challenges and ups and downs of breeding, dealing with formal requirements, guiding new breeders through health testing their dogs, and eventually helping them choose a suitable stud dog or bitch for their first litter or stud service.

In a rare breed, we regard mentorship not as an optional courtesy but as the primary method by which knowledge, ethics, and practical skills are passed on to the next generation of breeders. It is a mechanism that ensures continuity, safeguards quality, and prevents new breeders from feeling isolated or overwhelmed.

5.3 Building an international preservation network

On the international stage, we could consider forming a Canaan Dog preservation group or initiative, for example in order to:

- collect population data, including health and genetics
- discuss breeding strategies
- help one another find a stud dog, import a puppy, or import semen
- encourage and facilitate international co-breeding
- address challenges, both inherent to the breed and external
- produce educational and promotional materials (e.g., "Life with a well-socialised Canaan Dog", "Working with a Canaan Dog")
- build an online archive of historic Canaan Dog material

The overall goal of such an endeavour would be to support the breeding community and to make life just a little easier for new breeders. Given our overall challenges as breeders, such an initiative should probably begin not as a huge undertaking, but as a step-by-step project with a manageable level of effort for everyone who is interested in contributing.

Because each regional population is genetically limited, it could be helpful for new breeders to be invited into the international network from the beginning. This would give them access to a

[18] This is no longer the case in Germany, unfortunately. There are very few dog shows left, more are cancelled each year, and even when they do take place, only two or three Canaan Dogs are usually present.

broader pool of experience and breeding options, and would help them start their journey with confidence and good support.

5.4 Conclusion

Ultimately, the future of the Canaan Dog depends not only on genetic management, responsible breeding practices, and careful conservation planning, but on the people willing to carry these responsibilities forward. Responsible breeders are another vital, yet scarce resource in a critically small population, and supporting and mentoring new breeders is therefore not an optional task, but a central pillar of preservation. Only by guiding committed newcomers into the community can we ensure that the breed's unique heritage, health, and genetic diversity continue into the next generations.

To quote *Star Trek* one last time: "To them and their posterity will we commit our future."[19]

Practical Recommendations for Recruiting and Supporting New Breeders

- **Actively look for potential new breeders:** identify owners that show commitment, curiosity, and a long-term interest in the Canaan Dog.
- **Share knowledge openly:** the more transparent we are about our challenges, successes, and failures, the more informed and resilient our prospective new breeders will be.
- **Provide structured mentorship:** offer guidance on behaviour, training, genetics, health, and responsible breeding practices.
- **Encourage diversity-focused breeding goals:** teach new breeders to prioritise N_e, genetic diversity, and low-kinship over aesthetics.
- **Support first litters:** assist with planning, whelping, socialization, and puppy placement to reduce overwhelm in new breeders.
- **Offer access to high-quality breeding dogs:** sharing and co-owning promising Canaan Dogs helps new breeders contribute to the preservation of the breed.
- **Encourage participation in clubs and shows:** show new breeders how to own your failures, celebrate your successes, and connect with our community.
- **Overall, promote a culture of cooperation, not competition:** new breeders can only thrive in supportive networks rather than hierarchical or territorial environments.

Conclusions and Call to Action

The Canaan Dog stands at a crossroads. The breed's effective population size is already below the threshold considered safe for long-term survival. Its genetic structure is fragile enough that every breeding decision can carry population-level consequences. Interest from puppy buyers is declining, and so is the number of breeders. Yet there is hope.

If we work together, the Canaan Dog can remain a viable, healthy, and recognisable breed for generations to come. This will require coordinated management of its effective population size, the thoughtful use of genomic tools, informed mitigation of health risks, and an ongoing commitment to treating the global population as one breed. The continued existence of free-living

[19] Captain James T. Kirk in *Star Trek VI: The Undiscovered Country*. Paramount Pictures, 1991.

desert dogs in Israel offers a rare opportunity to strengthen the breed's genetic foundation. Used responsibly, they are not a divergence from the breed — they are part of its origin and its resilience.

Preserving the Canaan Dog must be a collective effort. No single enthusiast, breeder, club, or country can secure the breed's future alone. I would love to hear about your experiences with the Canaan Dog, insights from your breeding, feedback to what I have tried to say here, suggestion on further action — anything that might help carry our cause forward.

Every Canaan Dog is a treasure, a piece of living history. The decisions we make today, together, will determine whether it remains not only part of our past and present, but part of our future.

Although many of the principles and strategies discussed here may already be known to readers, I hope that this paper, together with the data presented, effectively conveys the precarious status of the Canaan Dog and motivates future action. We would like to emphasise once again our deep gratitude for the cooperation of our fellow breeders, who were all happy to share their information. We welcome any feedback, additions, or amendments.

Thank you for your engagement and your interest in the Canaan Dog.

Jens Hildebrand, July 2026

Recommended further reading:

1. Body size, inbreeding, and lifespan in domestic dogs. Jennifer Yordy, Cornelia Kraus, Jessica J Hayward, Michelle E White, Laura M Shannon, Kate E Creevy, Daniel E L Promislow, Adam R Boyko. June 30, 2020.
https://pmc.ncbi.nlm.nih.gov/articles/PMC7326369/

Discussion (excerpt): "Our results show that although large-breed dogs tend to have increased levels of inbreeding compared to small breeds, the reduced life expectancy of large dogs is driven by body size and not inbreeding depression. Furthermore, variation in inbreeding across dog breeds does not appear to be related to current breed population size. It should be noted, however, that census population size does not equal effective population size, and this inbreeding variation is likely related to breed differences in the strength of inbreeding at breed creation (founder effects) and/or differences in modern or historical breeding practices (e.g. use of popular sires). Our finding that body size and average level of inbreeding are positively correlated, particularly when considering inbreeding in the female line (…), supports the conclusion that breeding practices do affect inbreeding variation across breeds. Specifically, since large breeds have larger litters (Borge et al. 2011), it is likely that fewer females reproduce in large breeds compared to small breeds, leading to reduced female effective population size and increased inbreeding. Sex-specific differences in reproductive behavior, such as polygyny in natural populations or the use of popular sires in domestic animal breeding, lead to differences in sex-specific effective population sizes. Our finding comes as both a contrast and a complement to past emphasis on popular sire effects in driving inbreeding-related problems in domestic animals (Leroy 2011). As dog breeders increasingly strive to establish breeding regimes that prioritize population health and sustainability, it will be important to consider female effective population size as well as limiting the use of popular sires. (…)

Although inbreeding alone cannot explain patterns of deleterious genetic variation or inter-breed differences in fitness and longevity, this is not to say that it plays no role in the health or longevity of dogs. Indeed, our results both at the individual level and in comparing purebred versus mixed breed dogs indicate that inbreeding can have a highly significant effect on lifespan. Mixed breed dogs lived 1.2 years longer, on average, than size-matched purebred dogs (consistent with findings from Patronek et al. 1997), while outbred golden retrievers (CoI < 2%) were significantly longer-lived than inbred golden retrievers. (…)

A recent study found that the increased genetic load in domestic dogs compared to gray wolves results from past bottlenecks, not recent inbreeding (Marsden et al. 2016). The authors of that study analyzed genome-wide patterns of deleterious variation and performed simulations to test whether various demographic models would produce the observed patterns. They found that even a high level of inbreeding in recent years (i.e. since the establishment of modern breeds) could not sufficiently explain the observed patterns of deleterious genetic variation without the effects of population bottlenecks at domestication and breed formation. Although we did not directly assess genetic load, our findings that (1) breed-average inbreeding is not related to current census population size and (2) traits with deleterious health effects such as brachycephaly are linked to historic inbreeding (i.e. from bottlenecks at breed formation), are consistent with the conclusions of Marsden et al. (…)

Our conclusions in this study have direct applications for management of small populations to preserve genetic diversity and avoid inbreeding depression. These findings apply to managed breeding of endangered species (e.g. ex situ conservation programs) as well as the breeding of domestic animals, and can be summed up with the following:

The reproductive output of individual females should be monitored and kept equal as much as possible to avoid loss of genetic diversity due to small female N_e, especially in species or breeds that produce large litters.

Occasional crosses of animals from separate breeding pools (comparable to cross-breeding dogs or transfers of animals between separately managed international ex situ populations) can produce strong improvements in health and fitness.

Unless detrimental traits are actively maintained in a population, fitness impacts of historical inbreeding may be mitigated by natural processes over time, as long as further close inbreeding is avoided."

2. The effect of inbreeding, body size and morphology on health in dog breeds. Danika Bannasch, Thomas Famula et al. December 2, 2021.
https://pmc.ncbi.nlm.nih.gov/articles/PMC8638537/

Conclusions (excerpt): "Careful management of breeding populations to avoid additional loss of existing genetic diversity, through breeder education and monitoring of inbreeding levels enabled by direct genotyping technologies, is essential. (…) In particular, in the few breeds with low inbreeding levels, every effort should be made to maintain the genetic diversity that is present. While history has shown how easily it can be lost in closed breed populations, encouragement can be found in breeds exemplifying a consistent and true-breeding type without high inbreeding levels."

3. Heterozygosity testing and multiplex DNA panel screening as a potential tool to monitor health and inbreeding in a small, closed dog Population. S F A Keijser, H Fieten, M Vos-Loohuis et al. December 28, 2018.
https://pmc.ncbi.nlm.nih.gov/articles/PMC6309085/

Conclusions (excerpt): "Increased inbreeding of (sub) populations of a dog breed, carries the risk of inbreeding depression and increase of allele frequency of disease-causing, usually recessive alleles. Increasing heterozygosity, whilst maintaining characteristics important for the breed, and prevention [-> *preventing*, J. H.] the segregation of disease-causing gene mutations may be important in a sustainable, healthy breeding program.

Genetic relationship measurements can be used to match breeding couples to increase the genetic diversity in a breed population or in subpopulations within a breed. The multiplex DNA panel screening can be used to check for genetic disorders in the breed that were previously unknown and could potentially spread unintendedly in the population.

A sensible breeding programme should include application of the described genetic tools with appropriate counselling, as well as individual and population-based clinical screening for disorders with and without a known mutation."

4. Trends in genetic diversity for all Kennel Club registered pedigree dog breeds. T W Lewis, BM Abhayaratne, S C Blott. September 21, 2015.
https://pmc.ncbi.nlm.nih.gov/articles/PMC4579366/

Results/conclusion (excerpt): "The trend over all breeds was for the rate of inbreeding to be highest in the 1980s and 1990s, tending to decline after 2000. The trend was comparable in very common and rarer breeds, although was more pronounced in rarer breeds. Rates of inbreeding over the entire period 1980–2014 were not correlated with census population size. The existence of popular sires was apparent in all breeds.

The trends detected over 1980–2014 imply an initial excessive loss of genetic diversity which has latterly fallen to sustainable levels, even with modest restoration in some cases. The theory of genetic contributions, which demonstrates the fundamental relationship of inbreeding and selection, implies that popular sires are the major contributor to high rate of inbreeding."

6. Genetic prevalence and clinical relevance of canine Mendelian disease variants in over one million dogs. Jonas Donner, Jamie Freyer, Stephen Davison, et al. February 27, 2023.
https://pmc.ncbi.nlm.nih.gov/articles/PMC9997962/

Discussion/conclusions (excerpt): "Another notable observation compared to our prior canine disease variant screening studies is that with the increase of the number of tested variants to 250, it is now more common than not for a dog to carry at least one variant potentially influencing disease risk (57.2% of dogs). This estimate highlights how management of inherited disease in breeding programs of purebred

populations requires thorough screening of known disease-associated variants with a particular focus on the variants that are most relevant within each breed, combined with simultaneous consideration of genetic diversity and the viability of the gene pool in breeding selection.

We (…) have previously shown that breeds with higher-than-average inbreeding levels required greater amounts of veterinary care on average, and that purebred dogs as a group are more likely than mixed breed dogs to be homozygous for a common recessive disease-associated variant. In the present study, we have for the first time been able to evaluate the correlation between a molecular measure of genome-wide inbreeding and overall Mendelian disease variant load on an individual level. We most notably observed a relationship, albeit one with a small correlation coefficient, between genome-wide reduction in genetic diversity and an increased risk of homozygosity for multiple autosomal/recessive disease-associated variants in dogs. This finding provides a direct measurement-based example of how increased genomic homozygosity, e.g. as a consequence of the mating of close relatives in a closed gene pool, could contribute to driving inbreeding depression through the accumulation of deleterious recessives.

In conclusion, we report that it is relatively common for a dog to be at least heterozygous for one of the many known putative canine disease variants, while the majority of individual variants are very rare in the overall population. While many variants are enriched in specific breeds and absent from others, we conclude that health issues caused by Mendelian disease-associated variants are broadly shared across both mixed and purebred populations, as we find that several variants cause similar signs of disease independently of breed ancestry. Understanding of the clinical relevance of variants that are already targets of commercial genetic tests represents an important advance towards creating a variant significance classification system for dogs and contributes to the enablement of precision medicine. As more disease-associated variants are identified and screened in the future, it is likely to become inevitably clear that all dogs carry a number of deleterious recessive alleles. Maintenance of population diversity through sustainable breeding selections, outcrossing programs, and avoiding the overuse of specific popular sires represents a simple remedy that keeps breeds viable by counteracting the augmentation of recessive disease alleles."

7. Assessing the impact of breeding strategies on inherited disorders and genetic diversity in dogs. Grégoire Leroy, Xavier Rognon. June 18, 2012.

https://www.vin.com/Proceedings/Downloads/TuftsBG2013/90649_BreedStrategies_A6_Leroy_TuftsBG2013.pdf

Conclusions (excerpt): " Management of genetic diversity constitutes an important issue for controlling the dissemination of inherited diseases and hence the welfare of dogs. In the present study, we used kinship to investigate the evolution of genetic diversity, since it is a key component of breed conservation (Baumung and Sölkner, 2003) and is directly related to the number of founder genome equivalents, i.e., theoretical remaining alleles inherited from founders (Caballero and Toro, 2000). Therefore, the risk of spreading new inherited disorders is proportional to kinship increase. (…)

The simulation method developed here sought to assess the impact of different breeding strategies on the frequency of a deleterious allele and on genetic diversity for four French dog breeds. By simulating changes occurring within a pedigree file after implementation of a chosen breeding strategy, we have provided breed-specific recommendations relating to issues such as the removal of an inherited disease or limitation of number of offspring per reproducer. The choice of a given strategy is also highly dependent on the existence of other traits to be selected, such as those related to behaviour and to severity of the disease. For a same frequency, a disease with a dramatic impact on viability will likely require a stricter breeding policy than a mildly deleterious one. Adaptation of the procedure to more complex situations (more complex inheritance, segregation of several diseases) could be the subject of further studies."

8. Reconstructing the history of founder events using genome-wide patterns of allele sharing across individuals. Rémi Tournebize, Gillian Chu, Priya Moorjani. June 23, 2022. https://journals.plos.org/plosgenetics/article?id=10.1371%2Fjournal.pgen.1010243

Discussion (excerpt): "We show the wide applicability of our approach to non-human species by applying ASCEND [= *Allele Sharing Correlation for the Estimation of Non-equilibrium Demography*, J.H.] to the domesticated dog species. Among the 42 unique populations that we analyzed, all breed dogs and two village dog populations had significant evidence for a recent founder event. These founder events may be due to: (i) inbreeding that involves mating between closely related individuals, or (ii) the sire effect whereby only a very few highly valued individuals (based on selected phenotypic traits) are bred repeatedly and contribute disproportionately to the next generations. Such strong founder events can lead to high rates of homozygosity, and in turn increased risk of diseases. In accordance, some breeds like Boxers and Bulldogs that have among the strongest founder events in our analysis are also known to be affected by high rates of recessive diseases. (...)

We found the temporal distribution of founder events in dogs (~75–125 years ago) overlaps with the Victorian era when a large number of modern dog breeds were created in Great Britain in the context of popularizing dog-fancying and showing. Our results are consistent with a recent study that measured IBD and ROH patterns in ~4,000 breed dogs and found severe bottlenecks in most breeds."

9. DNA Health Testing Considerations. Claire Wiley, VMD, DACVIM (SAIM). September 19, 2023. https://www.akc.org/expert-advice/dog-breeding/dna-health-testing-considerations/

Quote: "Instead of testing for everything available, breeders should focus on DNA health problems that occur within their breed. Parent clubs have come together to determine relevant problems in their breed, and their health statements are posted on akc.org (https://www.akc.org/breeder-programs/breed-health-testing-requirements/). Recommendations are based on historical knowledge and experience of expert breeders and are used for AKC® Breeder of Merit and AKC® Bred with Heart certifications. Many clubs choose to perform health surveys to determine how common diseases are in their breeds. Breeders may also find specific problems within their lines, so these parent club health statements may not include every test a breeder may want to screen for. Meticulous record keeping and receiving follow up from owners helps track health problems that occur within a specific line."

10. Pet genomics medicine runs wild. Moses, Lisa; Niemi, Steve; Karlsson, Elinor K. Nature. 2018 Jul; 559 (7715): 470-472. https://www.nature.com/articles/d41586-018-05771-0

Quotes: "Pet genetics must be reined in. If not, some companies will continue to profit by selling potentially misleading and often inaccurate information; pets and their owners will suffer needlessly; and opportunities to improve pet health and even to leverage studies in dogs and cats to benefit human health might be lost. Ultimately, people will become more distrustful of science and medicine. (…) In principle — with large, well-powered studies, involving perhaps tens of thousands of animals — genetic testing could be used to predict the risk of common diseases affecting millions of pets (…).

To bring the untamed wilderness of pet genetic testing under control, we propose five steps. (…)

Establish standards. (…) Create guidelines. (…) Share data. (…) Recruit tools and expertise. (…) Educate counsellors. (…) In the United States alone, some 70% of households own pets. Done right, the use of genetic testing in companion animals could be a powerful way to better connect people to the possibilities of genetics for treating disease. Done wrong, it could erode trust in science for an increasingly sceptical public."