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Psammobates geometricus (Linnaeus 1758) –
Geometric Tortoise, Geometrische Skilpad, Suurpootjie

ERNST H.W. BAARD, MARGARETHA D. HOFMEYR,
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***Psammobates geometricus* (Linnaeus 1758) –
Geometric Tortoise, Geometrisse Skilpad, Suurpootjie**

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SUMMARY. – The Geometric Tortoise, *Psammobates geometricus* (family Testudinidae), is a small tortoise from southwestern South Africa (female straight-line carapace length [SCL] up to 16.5 cm, male SCL up to 12.3 cm; adult females average 1.2 times longer and twice as heavy as males). It is one of three recognized “starred” tortoises of the genus *Psammobates* of the southern African sub-continent and has the smallest distribution among them. It is endemic to landscapes in the Western Cape Province of South Africa, where small, highly fragmented and isolated populations are exposed to numerous threats, including habitat loss, fragmentation, degradation, and destruction. Geometric Tortoises are restricted to the “renosterveld” ecoregion of the Fynbos Biome of South Africa. Hatchlings and juveniles grow rapidly until ca. 8–9 cm SCL, whereafter growth slows considerably. Males reach sexual maturity at ca. 8–10 years and females at ca. 11–13 years. Home range size varies considerably depending on season and sex, and fragmented, suitable habitat patches, with small, non-viable populations, are often smaller than the home range size of one tortoise. Females produce 1–5 eggs per clutch and may lay more than one clutch per year. Body condition and hematology are influenced by environmental conditions. Food plants are selected based on nutritional value (e.g., soluble carbohydrates and phosphorus) and low biomechanical costs (tensile strength). The Geometric Tortoise is on the brink of extinction and is one of the most critically endangered tortoise species in the world. The survival of *P. geometricus* in the wild is threatened by habitat destruction for dryland and deciduous fruit agriculture, viticulture, avian and mammalian predation (corvids, baboons and honey badgers), invasive alien woody and herbaceous plants, overgrazing and trampling by domestic stock, droughts and wildfires. The species is fully protected by regional (Western Cape Province) and national (South Africa) biodiversity legislation, as well as listed by international conventions (IUCN Red List and CITES); however, small, isolated populations remain highly vulnerable to poaching and extermination by stochastic events. Conservation measures include effective land management, threat mitigation, enhancement of reproductive output, adult female and first-year survival, and securing more land under formal protection. Declaring biodiversity stewardship contract reserves is needed to maintain existing populations and viable habitat on private land and in a network of protected areas. A completed Species Conservation Plan (final draft under review) will coalesce interested and affected parties in securing a future for the species.

DISTRIBUTION. – South Africa. Restricted to the “renosterveld” ecoregion of the Fynbos Biome of Western Cape Province, South Africa.

SYNONYMY. – *Testudo geometrica* Linnaeus 1758, *Chersine geometrica*, *Hydrone geometrica*, *Psammobates geometricus*, *Peltastes geometricus*, *Peltastes geometrica*, *Peltastes (Chersinella) geometrica*, *Chersinella geometrica*, *Psammobates geometrica*, *Geochelone geometrica*, *Testudo luteola* Daudin 1801, *Peltastes geographicus* Gray 1869 (*nomen novum*), *Testudo geographica*, *Testudo strauchi* Lidth de Jeude 1893, *Chersinella strauchi*.

SUBSPECIES. – None recognized.

STATUS. – IUCN 2026 Red List: Critically Endangered (CR A4ace; 2018); CITES: Appendix I (1975); South Africa: National Environmental Management, Biodiversity Act 10 of 2004: Endangered; Western Cape Province: Western Cape Biodiversity Act 6 of 2021: Critically Endangered; US ESA: Endangered (1976).



Figure 1. Adult Geometric Tortoise, *Psammobates geometricus*, Western Cape Province, South Africa. Photo by Ernst H.W. Baard.

Taxonomy. — The Geometric Tortoise, *Psammobates geometricus* (Figs. 1–3), has a colorful and complex taxonomic history. It holds the distinction of being the first of the thirteen currently recognized South African land tortoise species to be formally described by Carolus Linnaeus, although the description actually referenced a specimen of what has subsequently been identified as an Indian Star Tortoise, *Geochelone elegans*, from Asia.

The official nomenclaturally available description of *Testudo geometrica* by Linnaeus (1758) was brief, noting only the most obvious characteristics. A translation from Latin reads: “*geometrica. T[estudo]* with webbed hind feet, shell with raised, truncated scutes. Shell black with yellow scutes emitting yellow anastomosing rays.” The specimen was stated to have come from Asia. However, an earlier description of the same specimen was by Linnaeus (1745), where he described several reptiles and amphib-

ians donated to the Uppsala Museum by Carl Gyllenborg, who had obtained his specimens from Asia. In that paper, specimen no. 24 (Fig. 4) was described more fully as follows (translated from Latin): “*Testudo picta vel stellata*. [Tortoise painted or starry]. The upper shell is black, wonderfully patterned with a yellow network, three times larger than the preceding and more convex, consisting of as many plates of both margin and disc. The disc of the shell is very convex, consisting of plates distinct from one another by deeper cavities and grooves, than the preceding ones. The individual plates are quite convex, blunt at the apex, yellow, with the center obscurely dotted, angular at the sides, black and striated, variegated with nine yellow lines running down. The breastplate is as in the preceding, but behind more bifid and pointed. The color of each plate is yellow, emitting from the circumference 9 or 10 broad, yellow lines, which in a singular manner join with the oth-



Figure 2. Adult male (left) and female (right) Geometric Tortoises, *Psammobates geometricus*, from the Cape Winelands, Western Cape Province, South Africa. Photos by Tyrone Ping.



Figure 3. Adult Geometric Tortoise, *Psammobates geometricus*, at the Southern African Tortoise Conservation Trust, Breede Valley, Western Cape Province, South Africa. Photo by Eric V. Goode / Turtle Conservancy.

ers.” Linnaeus (1749) later repeated the same description but modified the name of specimen no. 24 to “*Testudo (geometrica) picta vel stellata*” [Tortoise (geometric) painted or starry]. This specimen was later identified by Lönnberg (1896) as the type of *Testudo geometrica*.

The reason that Linnaeus (1758) had stated that his specimen of *T. geometrica* came from Asia was that it actually did come from there. In support of this, Wallin (1977) demonstrated that the Linnaean type specimen of *Testudo geometrica* in Uppsala University, Sweden (museum number UPSZTY 20; original Gyllenberg Collection, specimen no. 24) (Fig. 4), is in fact a large Indian Star Tortoise, *Geochelone elegans* from Asia, with a straight-line carapace length (SCL) of 24.5 cm (much larger than any Geometric Tortoise from South Africa). Wallin (1977) noted that, by strict priority, the name *elegans* would therefore need to be replaced by *geometrica*, and *Testudo luteola* Daudin 1801 could be used for the South African Geometric Tortoise, unless the senior synonym was suppressed under Article 79 of the International Code of Zoological Nomenclature, as it had not been used for more than 50 years.

Instead, the confusion surrounding the type specimen and what scientific name to use for the South African Geometric Tortoise vs. the Indian Star Tortoise was resolved by Hoogmoed and Crumly (1984), who, to conserve current usage and avoid nomenclatural instability, designated a pre-Linnaean illustration by Piso (1658) that Linnaeus (1758) had also referenced in his description of *T. geometrica* (as part of the composite syntype series), as the lectotype for *Testudo geometrica* Linnaeus 1758 [= *Psammobates geometricus*] (Fig. 5). They emphasized that if Wallin (1977) had designated the Uppsala specimen (= *G. elegans*) as the lectotype, the Indian Star Tortoise would have become *Geochelone geometricus*, while Daudin’s *T. luteola* would have become the valid name for the Cape species—an outcome that would have caused considerable taxonomic and conservation confusion.

It is noteworthy that Piso (1658) mentioned and illustrated a South African tortoise in his book on Brazilian natural history. Given close historical ties between Brazil and the Cape of Good Hope, both under Dutch occupation around this time, this may not be surprising (Hoogmoed and Crumly 1984).

Crumly (1988) noted that Daudin (1801) described *T. luteola* from a specimen acquired in Dieppe, northern France. He observed that the specimen was very similar to the Geometric Tortoise in carapace shape, head structure, and plastron configuration, though he noted narrower marginal shields, a smaller nuchal, and a narrower plastron. Despite these differences, Daudin’s specimen was confirmed to be *Psammobates geometricus* (Hoogmoed and Crumly 1984). Similarly, *Testudo strauchi* Lidt de Jeude 1893, housed in the Leiden Rijksmuseum, was identified as *P. geometricus* (Hoogmoed and Crumly 1984), though it exhibits an abnormally suppressed nuchal scute (R. Rau, pers. comm.).

Although the type specimen issue has been resolved, the supposed native origin of “*T. geometrica*” remained uncertain for many years. Authors such as Daudin (1801),



Figure 4. Type specimen of *Testudo geometrica* Linnaeus 1758 in the Linnaean collection at Uppsala University, Sweden (UPSZTY 20; Gyllenberg Collection, no. 24), identified by Wallin (1977) as an Indian Star Tortoise, *Geochelone elegans* (24.5 cm SCL), from Asia. Photo by Hans Mejlön.

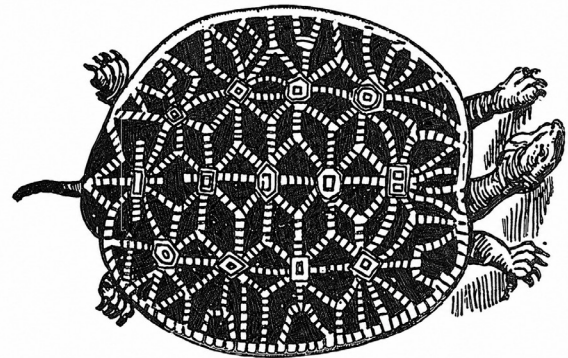


Figure 5. Pre-Linnaean illustration by Piso (1658) designated as lectotype for *Testudo geometrica* Linnaeus 1758 by Hoogmoed and Crumly (1984).



Figure 6. Hatchling *Psammobates geometricus*. Photo by Margaretha D. Hofmeyr.



Figure 7. Juvenile *Psammobates geometricus*. Photo by Margaretha D. Hofmeyr.

cited vague or erroneous localities, including “Asia,” “towards the Cape of Good Hope,” “Ascension Island,” and “common in the woods near Cape Town.” Thunberg (1788), the curatorial successor to Linnaeus at Uppsala University, was the first authority to erroneously describe *T. geometrica* as being native to the Cape of Good Hope region. In his travel logs, including from his expeditions from 1772 to 1775 through the Cape Forelands, Breede River Valley and the Ceres Valley, into the Roggeveld and Tankwa Karoo and southern Cape, he noted that (translated from Swedish): “*Testudo geometrica* was known here as *syrentje*. This land-tortoise, which evidently is the most beautiful of its kind, was commonly found in the sand dunes among the bushes,” presumably in the vicinity of Cape Town and the Cape Forelands towards the mountains. Shaw (1802) still questioned where *T. geometrica* originated (noting that various accounts suggested it occurred in Asia, Africa, and even the Americas), but also noted that Thunberg had found it common in the Cape of Good Hope. Gray (1831) subsequently indicated the distribution of *T. geometrica* as being the Cape of Good Hope and Madagascar, but later (Gray 1844) restricted its distribution to South Africa and Cape of Good Hope.



Figure 8. Adult female *Psammobates geometricus*. Photo by Ernst H.W. Baard.

Boulenger (1886) noted the species was “common in the Cape Peninsula” but did not emphasize its restricted distribution.

As such, the scientific name for an Indian Star Tortoise originating in Asia came to be erroneously regarded as the scientific name for the South African Geometric Tortoise, despite the statement by Linnaeus that his *T. geometrica* came from Asia. Fortunately, this has all been corrected and nomenclaturally stabilized by the designation of the illustration by Piso (1658) as lectotype of *Testudo geometrica* (Hoogmoed and Crumly 1984).

Duerden (1907) was the first to recognize the limited range of *T. geometrica* in South Africa, stating: “*Geometrica* is limited to the low districts around the south-western extremity of Cape Colony.” This corresponds closely to the species’ historic and current distribution (Rau 1971; Greig 1984; Baard 1993), and Baard (1991) formally restricted the type locality to “southwestern Cape Province, South Africa.” Following democracy in 1994, the South African “Cape Province” (= “Cape Colony” under British rule), was split partly into three provinces, one of which is now known as the Western Cape. Baard’s (1991) designated type locality could therefore technically read “restricted and endemic to the extreme southwestern part of the Western Cape Province, South Africa.”

Although originally described in the genus *Testudo*, the Geometric Tortoise has also been variously allocated to several other genera over the years. Merrem (1820) placed it in the genus *Chersine* and Fitzinger (1843) was the first to assign it to its currently recognized genus, *Psammobates*; however, it has also been assigned briefly to *Peltastes* (Gray 1869, 1870), *Chersinella* (Hewitt 1933), and *Geochelone* (Obst 1980).

Greig and Burdett (1976) proposed that the *Psammobates* taxa fall into two groups, namely the *geometricus-oculifer* pair and the *tentorius* complex. More recently, Hofmeyr et al. (2017a) confirmed a sister relationship between *Psammobates* and *Stigmochelys* within one of three clades of Southern African endemic tortoises. *Psammobates geometricus* and *P. oculifer* are sister spe-

cies, sharing a common ancestor dating back to the Early Miocene, approximately 21.6 Mya, although *P. tentorius* geographically separates them.

Climatic fluctuations in the Greater Cape Floristic Region, following the Middle Miocene Climatic Optimum (15–17 Mya), were marked by long-term cooling, intensified glacial–interglacial cycles, repeated sea-level oscillations, and progressive aridification of the southwestern subcontinent (Tolley et al. 2014, and references therein). The establishment of the proto-Benguela Current (ca. 10–14 Mya; intensifying ca. 3–5 Mya) further altered rainfall seasonality, producing an austral Mediterranean climate characterized by pronounced summer aridity in the west. These shifts strongly influenced species distributions, driving repeated contractions, expansions, and range shifts in, for example, several plant clades from the Cape Floristic Region (Hoffmann et al. 2015), *Chersina angulata* (Daniels et al. 2007), *Homopus areolatus* (Hofmeyr et al. 2020) and the Cape Girdled Lizard, *Cordylus cordylus* (Mouton and Oelofsen 1988). Baard and Mouton (1993) argued that the origin of *P. geometricus* can be envisaged in a manner analogous to scenarios proposed for *C. cordylus* and its cold-adapted congeners.

No subspecies of the Geometric Tortoise have been described, and none are currently recognized. Earlier conservation genetic research using microsatellite DNA found no significant genetic divergence among three seemingly isolated subpopulations (Cunningham et al. 2002). Ongoing studies are now applying updated genetic methodologies and analyses with particular focus on conservation concerns such as inbreeding depression and reduced genetic variation (M. Vamberger, pers. comm.).

Description. — *Psammobates geometricus* is a small species, with straight-line carapace length (SCL) up to 16.5 cm in females and 12.3 cm in males, adult females being approximately 1.2 times longer, and twice as heavy as males (Baard 1990; Henen and Hofmeyr, unpubl. data).

Size and Weight. — Baard (1995a) reported that adult male Geometric Tortoises (Fig. 2, *left*) from the Elandsberg Private Nature Reserve averaged ($\pm$ SD) 105.2 $\pm$ 9.4 mm straightline carapace length (SCL; range 84.7–123.4; n = 80), and 208.3 $\pm$ 44.1 g body mass (range 124–320; n = 80), while adult females (Fig. 2, *right*) averaged 123.2 $\pm$ 9.4 mm SCL (range 88.6–142.5; n = 89), and 410.4 $\pm$ 86.8 g body mass (range 161–680; n = 89). The dimensions of the biggest male and female were 123.4 and 142.5 mm SCL, and 320 and 680 g mass, respectively. The mean size of hatchlings is 28.1 $\pm$ 1.0 mm SCL (n = 10) (Fig. 6) and juveniles range from approximately 30–80 mm SCL (Fig. 7).

Baard (1992a) provided basic morphometric and numeric data on Geometric Tortoises from five localities in the southwestern Cape, namely the Elandsberg Private Nature Reserve, the Eenzaamheid Provincial Nature Re-

serve (= J.N. Bries-Louw Contract Nature Reserve), the Harmony Flats Provincial Nature Reserve (= Hottentots Holland), a farm in the Ceres Valley, and a farm in the Worcester/Tulbagh area. Males (n = 67) ranged from 110.2–116.6 mm SCL, 55.1–59.3 mm carapace depth (CD), 76.3–79.2 mm carapace width (CW), 220.3–255.4 g mass, and 2,448.3–2,800.5 mm³ body volume. Females (n = 65) ranged from 117.9–134.9 mm SCL, 67.0–76.2 mm CD, 87.0–99.9 mm CW, 349.7–501.6 g, and 3,651.9–5,434.8 mm³. Baard (1992a) concluded that a) individuals from Elandsberg appeared to be somewhat smaller (though not statistically significant), than those from the other populations, b) Elandsberg female carapace depth differed significantly from that of Eenzaamheid, Harmony Flats, Ceres and Worcester, c) Elandsberg female volume differed significantly from Eenzaamheid, Ceres, and Worcester, and d) individuals from Harmony Flats had significantly more vertebral rays than the other populations.

Other authors reported that males average 100 mm SCL, reaching up to 129 mm, and with a carapace depth of approximately 60 mm. Rau (1976) recorded the largest male with 111 mm SCL. Males typically weigh 200–270 g, though very large males of up to 376 g have been recorded. Females averaged 125 mm SCL, reaching 138 mm to 165 mm, with a carapace depth of 90 mm. Rau (1976) recorded the largest female found with 154 mm SCL. Female average weight is approximately 430 g, but very large females can weigh between 680–850 g (Boycott and Bourquin 2000; Branch 2008; Kiester et al. 2023; J. Austin, unpubl. data; Hofmeyr, unpubl. data).

Carapace. — The shell is domed and convex, never flattened dorsoventrally, with steep sides and a deep anterior notch. Vertebral and marginal scutes are typically raised and slightly truncated. The nuchal scute is usually longer than wide. In some individuals, scutes are markedly raised, giving a tent-like appearance. Carapace scute arrangement includes 1 nuchal, 5 vertebrals, 4 pairs of costals, 11 marginals on each side, and 1 undivided supracaudal (see Fig. 2). Abnormalities are rare but may include 2 nuchals, 6 vertebrals, 5 costals, or 10–12 marginals (Keswick 2012). Marginal scutes on the bridge are characteristically higher than wide (distinguishing it from *P. tentorius*), with only slightly upturned posterior margins (distinguishing it from *P. oculifer*) (Boycott and Bourquin 2000; Branch 2008; Hofmeyr et al. 2014).

Plastron. — The plastron is relatively large with a shallow anterior notch. Plastron scute arrangement includes paired gulars (wider than long), humerals (not contacting the single axillary on each side), pectorals, abdominals, femorals (in contact with the inguinals) and anals (see Fig. 2). The central seam between the pectorals is usually the shortest, though occasionally the anal seam is shorter. Adult males exhibit a distinct plastral concavity (Boycott and Bourquin 2000; Branch 2008).

Head, Limbs, and Tail. — The head is moderate in size, with a rounded snout, tricuspid beak, and small scales, except for a divided prefrontal and subdivided frontal (Fig. 8). The forelimbs have five clawed toes, while the hind limbs have four. Buttock tubercles are absent, and the tail lacks a terminal spike (Boycott and Bourquin 2000; Branch 2008).

Coloration. — The carapace displays a striking geometric pattern with bright yellow rays radiating from scute centers across a shiny black background. Vertebral scutes individually bear 8–15 rays, costals 9–12, and marginals 2–4. Juveniles often show symmetrical ray patterns forming perfect geometric designs. Though further growth generally disrupts this symmetry, sub-adults and adults with perfect geometric designs are found occasionally. Hatchlings differ in coloration, with orange to brown rays that turn bright yellow within 1–2 years (see Figs. 6 and 7). Some hatchlings are predominantly yellow or bear a single yellow “X” on each shield, with the radial pattern developing later. The plastron may be pale yellow with a dark central region or predominantly dark with a narrow yellow margin. Yellow rays may occur on humeral, abdominal, and femoral shields. The head, neck, limbs, and tail are yellow with small black patches (Fig. 8) (Boycott and Bourquin 2000; Branch 2008).

Sexual Dimorphism. — Adult males are smaller than adult females and differ in shell profile, supracaudal scute shape, tail length, and plastral concavity. Compared to females, the back of the male shell slopes gradually towards a rounded, bulbous supracaudal scute. Adult male tails are longer, broader, and taper evenly, often extending to or beyond the anterior edge of the last marginal scute. Compared to males, the back of the female shell slopes steeply and abruptly towards a flattened supracaudal shield. Adult female tails are shorter, taper abruptly, and rarely extend beyond the supracaudal edge. Male plastral concavity, approximately 2–3.5 mm deep (Baard 1995a), involves most of the abdominal scutes and the anterior portion of the femoral scutes (Rau 1971; Baard 1990; Boycott and Bourquin 2000; Branch 2008).

Distribution. — Geometric Tortoises historically occupied three neighboring, yet isolated, Western Cape landscapes: the Cape Forelands, locally known as the “Swartland” (west), the Upper Breede Valley (central), and the Ceres Valley (northeast) (Fig. 9) (Baard 1993; Baard and Mouton 1993). At the landscape level, these populations are separated by the Cape Fold Mountain Belt, formed during late Paleozoic and Permian plate collision, folding, uplifting and erosion creating the present mountain ranges. The Swartland and Upper Breede Valley are separated by the Olifantsrivier, Groot Winterhoek, Elandsloof, Hawequas, and Du Toitskloof ranges, while the Upper Breede and Ceres valleys are separated by the Skurweberg, Waboomsberg, and Witzenberg mountains (Cowling et al. 1997; Partridge and Maud 2000).

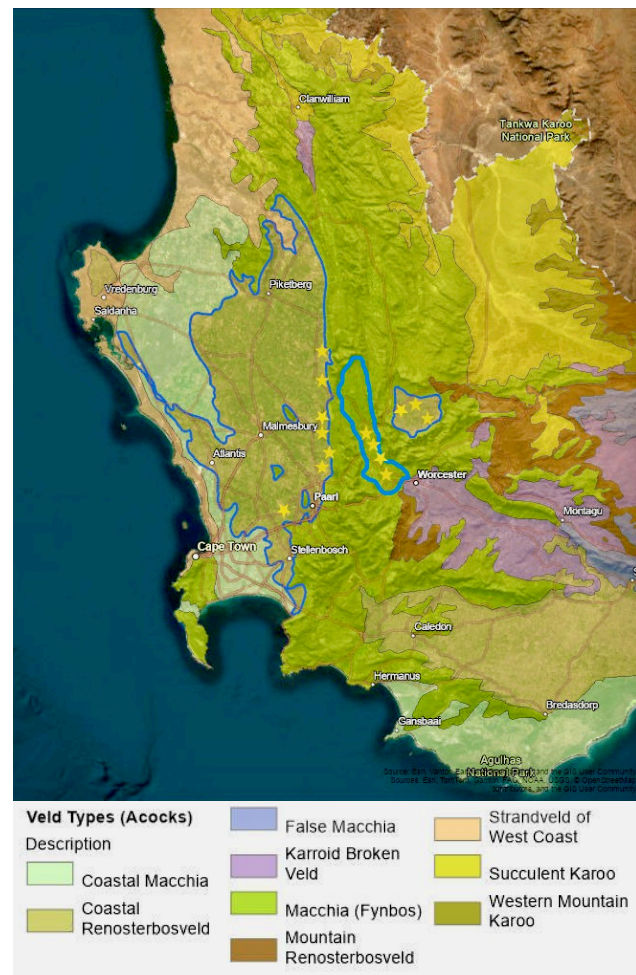


Figure 9. Historical extent of renosterveld (three polygons outlined in blue) and current distribution (yellow stars) of *Psammobates geometricus* in southwestern Western Cape Province, South Africa. Map by Western Cape Government.

Historically, the species was reported from around Eendekuil and Piketberg in the north, southwards through the Swartland (Porterville, Gouda, Hermon, Darling, Moorreesburg, Malmesbury, Wellington, Paarl) to the Helderberg-Strand-Gordon's Bay area in the south, eastwards in the Upper Breede River Valley, from Tulbagh and Wolseley in the north to just west of Worcester, as well as in the Ceres Valley to the northeast (Loveridge and Williams 1957; Rau 1971; Greig 1984; Baard 1989a, 1993; Baard and Hofmeyr 2014; Hofmeyr et al. 2014; Hofmeyr and Baard 2018).

The distribution of *P. geometricus*, in the broad sense, tracks the ecoregion known as “renosterveld” (= literally in English “rhinoceros veld”) (Acocks 1975; Mucina and Rutherford 2006; Baard and Hofmeyr 2014; Hofmeyr and Baard 2018) (Fig. 9), a sub-biome of the Fynbos Biome, one of nine plant biomes of South Africa and a major component of the world-famous Greater Cape Floral Kingdom, one of six plant kingdoms worldwide. Renosterveld comprises vegetation types such as and including Shale Renosterveld, Granite Renosterveld, and Alluvium Fynbos (Mucina and

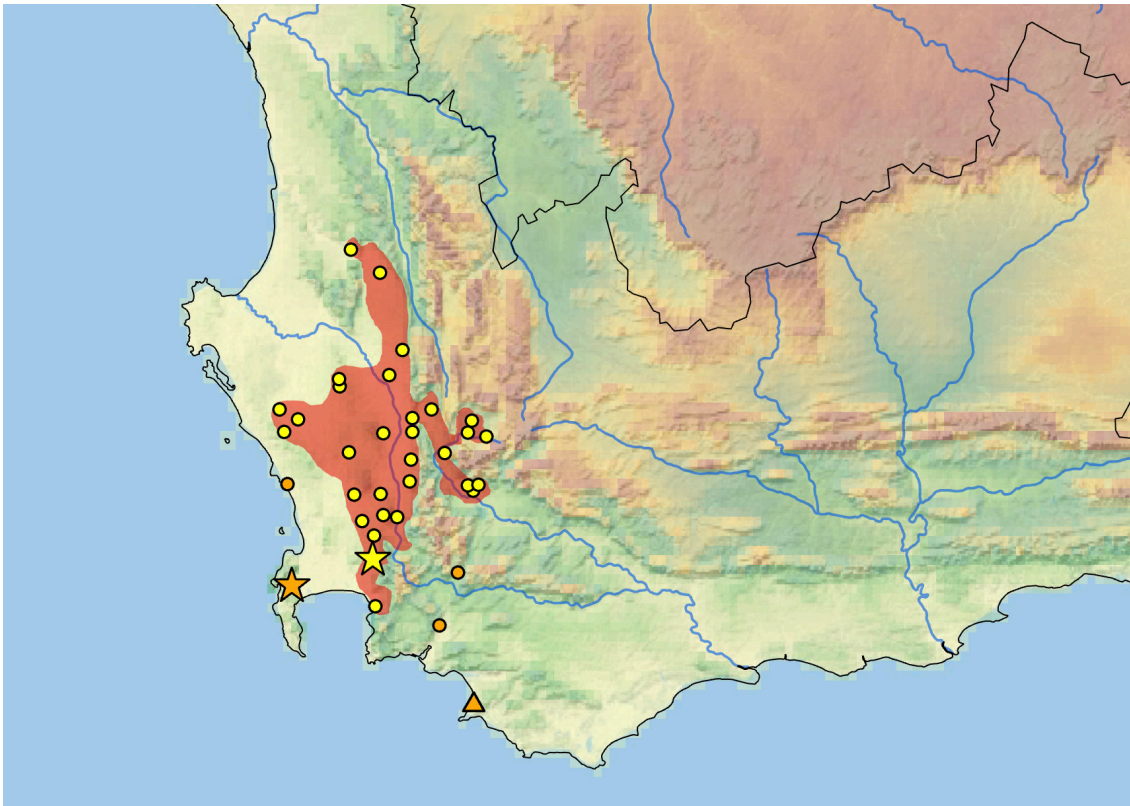


Figure 10. Estimated historical indigenous distribution of *Psammobates geometricus* in South Africa. Yellow dots = museum and current and historical occurrence records of presumed native populations based on literature and online records (TTWG 2025, in prep.); orange dots = possible relictual or other questionable records; orange triangle = archeological site; yellow star = restricted estimated type locality for *Testudo geometrica* Linnaeus 1758; orange star = type locality for *Testudo strauchi* Lidth de Jeude 1893 (probable trade specimen). Colored shading = estimated historical indigenous range. Distribution is based on fine-scaled GIS-defined level 12 HUCs (hydrologic unit compartments) constructed around native localities and then adding HUCs that connect point localities in the same watershed or physiographic region, and similar habitats and elevations as verified HUCs, based on TTWG (2025, in prep.) and then converted to an elevation-limited polygon and adjusted based on further data from the authors. Map by Chelonian Research Foundation.

Rutherford 2006; Skonow et al. 2019; Moncrieff 2021), primarily found in the Swartland, Upper Breede River Valley, and Ceres Valley. Following the extensive conversion of almost exclusive Geometric Tortoise habitat—namely Granite and Shale Renosterveld and Alluvium Fynbos—into dryland wheatfields and vineyards, the species' occupied range contracted markedly during the last century. Several isolated populations now persist only in the Paarl, Worcester, Tulbagh, and Ceres Administrative Regions of the Western Cape Province; in the rest of its original distribution range the species has been extirpated.

A summary of early records of *P. geometricus* by Loveridge and Williams (1957) indicated their presence in: “Cape Province: Cape Peninsula; Ceres; Darling; Eendekuil district; Klapmuts; Moorreesburg district; Porterville district; Riebeeck Kasteel” and reported their range as “Cape Province (Tulbagh, Paarl and Malmesbury districts of the extreme southwest, in former times possibly extending to the Cape Peninsula)” with no mention of the Ceres Valley.

Archer (1960, 1967) also confirmed the species' presence in the southwestern Cape Province, while Rau (1971)

expanded the known distribution with six new localities, including Het Kruis (Eendekuil), Bot River, the Hottentots Holland (Helderberg) basin (current Strand-Gordon's Bay area), and an archaeological record from De Kelders, Gans Bay (see below). Juvik (1971, 1972) confirmed Rau's (1971) localities, including the Ceres Valley, although considering the Ceres locality to possibly consist of ‘captive (?)’ specimens “with ultimate origin in doubt.”

Greig and Burdett (1976) stated that the species occurred in the western Cape coastal area between the mountains and the sea, making no mention of the inland populations in the Upper Breede River and Ceres valleys. Their distribution map (Greig and Burdett 1976:Fig.5), however, clearly showed the presence of the species in these two landscapes east of longitude 19°E. Greig and Boycott (1977) listed 17 localities in the general region they visited in 1976. Greig (1984) summarized and updated the distribution and status of *P. geometricus* and indicated 13 sites where the species was still found at that time, based on a research report by Greig and Boycott (1977).

Baard (1990, 1993) conducted extensive field surveys and interviews with landowners across the historic distri-

bution range of *P. geometricus* in the Swartland, Upper Breede River, and Ceres valleys, including the greater Breede River Valley southwards towards Villiersdorp and Bot River between October 1985 and September 1991. Several sites mentioned by earlier authors were revisited to verify the presence or absence of the species. In total, 67 sites were surveyed, and the results (Baard 1993) confirmed that the species was still present in at least 31 localities, including 22 newly verified sites in the Western Cape lowlands (Swartland, Upper Breede River, and Ceres valleys). Six localities had been destroyed during the preceding 14 years. At the time, five nature reserves supported various-sized populations of the species: one private reserve (Elandsberg Private Nature Reserve) and four provincial reserves (Voëlrvlei, Riverlands, Harmony Flats, and Eenzaamheid).

The only confirmed records of *P. geometricus* outside this general distribution reported above are those from De Kelders near Gans Bay (Rau 1971), the town of Darling (Loveridge and Williams 1957), and the Koeberg Nature Reserve (Baard, pers. obs.).

Rau (1971) recorded an approximately 2,000-year-old radiocarbon-dated Geometric Tortoise specimen in the Iziko South African Museum, Cape Town (formerly the South African Museum) from Klipgat Cave, at De Kelders near Gans Bay (Gansbaai), an important archaeological site that dates to the Middle Stone Age, with evidence of early modern humans, the Khoekhoen/Khoikhoi, living there approximately 70,000 to 80,000 years ago. It was argued that it is highly likely that this and other tortoise shells were carried and used there at the time by the Indigenous people, potentially as make-shift everyday objects such as bowls and spoons or made into toiletry boxes (e.g., buchu *Agathosma betulina* and *A. crenulata* containers), worn by women as jewelry (Rau 1969).

Based on the Klipgat Cave record, Rau (1971) argued that the historic range of the Geometric Tortoise may have included the Breede River Valley southwards towards the towns of Villiersdorp and Bot River, and possibly further south towards Gans Bay. This is based on evidence of human occupation of the cave during periods of lowered sea levels, with reliance on terrestrial fauna, such as tortoises, and shellfish as food. The cave's position above present-day sea levels means that during the Last Glacial Maximum and Younger Dryas periods, the shoreline extended much further out, altering resource accessibility. Excavations here have indicated an extensive presence of Angulate Tortoises, *Chersina angulata*, collected and consumed by early inhabitants (Klein and Cruz-Urbe 1983).

A subsequent survey of 12 localities in the Villiersdorp and Bot River region (Baard 1990, 1993) found only one dubious historic locality. Given its position between 11 other sites where no one recognized Geometric Tortoise shells, it is highly unlikely the species ever

occurred there. Instead, *C. angulata* and the Common Padloper, *Homopus areolatus*, were frequently observed and identified.

The “Darling” record (Loveridge and Williams 1957) is based on two specimens in the Port Elizabeth Museum, collected from this area by B. Peers and an unknown collector in March and April 1905, respectively (W.R. Branch, pers. comm.). No further locality data are available. The town of Darling lies within the historic distribution of Granite and Shale Renosterveld, and it is therefore likely that this species historically occurred there on the western extreme of its range, but has since been extirpated in the face of extensive land clearing for agriculture and viticulture.

A single record from the Koeberg Nature Reserve, north of Cape Town along the Western Cape coast, is based on a specimen photographed by the reserve manager and positively identified (Baard, pers. obs.) in January 1997. The reserve, near Melkbosstrand, lies within the Cape Flats Dune Strandveld and Atlantis Sand Fynbos vegetation types—habitats largely avoided by Geometric Tortoises—although small, isolated patches of Granite Renosterveld occur nearby. The current Koeberg Nature Reserve manager has confirmed no additional records (O. Peters, pers. comm.) for the species and given this last recorded observation and the degree of habitat deterioration in the general area, the recent, natural occurrence in the reserve or general area of a viable Geometric Tortoise population is deemed unlikely.

Following the vast expansion of wheat and wine grape farming and the clearing of thousands of hectares of pristine Geometric Tortoise habitat, that is, Granite and Shale Renosterveld and Alluvium Fynbos, the distribution of the species has diminished markedly and significantly (see below), and a number of isolated populations can now only be found in the Paarl district, north of Wellington towards Porterville, between Tulbagh, Wolseley and Worcester, and in the Ceres Valley.

Baard and Hofmeyr (2014) estimated the Extent of Occurrence (EOO) of the Geometric Tortoise at 4,034 km² (medium confidence) and the Area of Occupancy (AOO) at approximately 22 km² (high confidence) at that time. The latter was calculated using the summed area of minimum polygons around the three clusters of known locality sites.

Psammobates geometricus generally avoids steep, rocky, mountainous terrain and mountain slopes, and it was for this reason that Baard and Hofmeyr (2014) excluded this terrain from their AOO assessment, given that preferred Geometric Tortoise habitat comprises several fragmented and isolated (usually by tens of kilometers) lowland patches of remaining habitat. In contrast, Hofmeyr and Baard (2023) reported that the species' EOO had declined by just over 70%, from 9,800 km² historically to 2,750 km². They noted that in areas where the EOO had



Figure 11. Typical *Psammobates geometricus* renosterveld habitat. *Top left:* Elandsberg Contract Nature Reserve. Photo by Ernst H.W. Baard. *Top right:* Southern African Tortoise Conservation Trust, Breede Valley. Photo by Eric V. Goode / Turtle Conservancy. *Bottom left:* Ceres Valley. Photo by Ernst H.W. Baard. *Bottom right:* J.N. Briers-Louw (Eenzaamheid) Contract Nature Reserve. Photo by Yzelle Simmington.

contracted, Geometric Tortoises had not been recorded for decades. Due to the sensitivity of occurrence records, the revised distribution was presented only as quarter-degree grid cells, with the EOO estimated as 2,750 km² and the “distribution” (interpreted as AOO) estimated as 399 km².

Tolley and Alexander (2023a) explained that AOO is typically calculated as “the cumulative area of 2 × 2 km grid cells that intersect with locality records of suitable habitat.” This method likely accounts for the discrepancy between Baard and Hofmeyr’s (2014) AOO of 22 km² and Hofmeyr and Baard’s (2023) AOO of 399 km². The latter appears to include mountainous terrain within the grid cells, thereby inflating the estimate and presenting a somewhat misleading picture of the species’ actual AOO, and potential for suitable habitat for species recovery.

TTWG (2025) calculated the estimated historical indigenous distribution of *P. geometricus* (AOO) as ca. 6,261 km² and the original indigenous EOO as ca. 12,260 km², indicating a ca. 94–99% historical reduction in the AOO (Fig. 10).

Psammobates geometricus is not sympatric with its two congeners, *P. tentorius* and *P. oculifer*. The three subspecies of the Tent Tortoise—*P. t. tentorius*, *P. t. verroxii*, and *P. t. trimeni*, replace *P. geometricus* to the north and east of its range.

Habitat and Ecology.—*Psammobates geometricus* occurs in the Mediterranean climate region of southwestern South Africa (Fig. 11) with warm to hot, dry, and fire-prone summers (average daytime highs: 25–30°C [77–86°F]) and mild to cold, wet and rainy winters (average daytime highs around 17–20°C [62–68°F]) with a mean annual rainfall of 350–600 mm. It is found in evergreen, microphyllous shrublands of the southwestern part of the Western Cape Province at altitudes from near sea-level (historically in the Helderberg Basin) up to approximately 600 m (Baard 1995b). It occurs exclusively in the Fynbos Biome, one of nine floristic biomes of South Africa, inclusive of the Northwest and Southwest Fynbos Bioregions and primarily in the West Coast Renosterveld Bioregion (Rebelo et al. 2006; Mucina and Rutherford 2006). Its habitat (Hofmeyr and Baard 2018) comprises several Critically Endangered and Endangered vegetation types, including Alluvium Fynbos, Sand Fynbos, Shale Fynbos, Shale Renosterveld, Granite Renosterveld, and Silcrete Renosterveld (Fig. 9). Recent data indicate that Shale Renosterveld and Granite Renosterveld, characterized by the prominent presence of renosterbos (= “rhinoceros bush,” *Dicerothamnus rhinocerotis*), and Alluvium Fynbos in the Western Cape, are among the most heavily transformed vegetation types in South Africa. An estimated 90–94% of the collective

original distribution of *P. geometricus* has been completely and irreversibly converted to intensive dryland cultivation; the dominant crops including wheat, canola, and barley, along with extensive wine and table grape production. These ecosystems are classified as Critically Endangered or Endangered (South African Department of Forestry, Fisheries and the Environment 2022), reflecting the severe and ongoing habitat loss documented by Skonow et al. (2019) and Moncrieff (2021).

The preferred habitat of *P. geometricus* is fertile, shale-derived soils and topography well-suited to agriculture, and in the western coastal lowlands, occupies an intermediate position between coastal strandveld at lower elevations and sandstone- or granite-derived fynbos at higher altitudes. Strandveld is a broad-leaved shrubland that grows in calcareous coastal sands and on arid, granitic soils, whereas fynbos is a heathland dominated by proteoid, ericoid, and restioid growth forms on acidic, nutrient-poor, sandstone-derived soils of mountains and slopes. Moll et al. (1984) noted that, along an increasing moisture gradient, vegetation typically grades from strandveld along the coast through renosterveld to fynbos in the mountains. From a macro-habitat and landscape perspective, Geometric Tortoises are habitat specialists restricted to renosterveld, and do not use strandveld or true fynbos, unlike the sympatric tortoises *C. angulata* and *H. areolatus*, which are found in all three vegetation types.

The preferred micro-habitat of Geometric Tortoises is low-lying, undulating, well-drained, and relatively flat terrain, both at lower and higher altitudes. These areas are characterized by a dominant low to medium-high shrub layer, variable graminoid, restioid, and ericoid components, and an annual herbaceous understory. Their presence is generally negatively correlated with terrain slope and rockiness, which may restrict distribution, with stony, moderately steep sites in the Ceres Valley being an exception (Baard, Henen, Juvik, pers. obs.).

At Elandsberg Nature Reserve, tortoises avoid areas with extensive stone and rock cover and prefer damper microhabitats during the dry season (Baard 1995b). Key micro-habitat features at Elandsberg include medium vegetation height (50–100 cm), optimal shrub canopy cover (25–50%), and ground cover dominated by restioids (25–50%), succulents (5–10%), small proportions of perennial grasses (5–10%), and annual herbaceous plants (2–5%), with minimal stone and rock cover (<1%) (Baard 1995b).

In the Breede Valley, they favor shale-derived renosterveld with high bulb diversity, avoid vegetation that is moribund or over-aged, and occasionally use wetland margins (e.g., *Elegia* wetlands) during late spring and early summer, while tall restios such as *Willdenowia incurvata* provide both predator protection and suitable refugia in deep sand (Euston-Brown 2016).

Behavior and Activity. — Using thread-trailing, Henen et al. (2017) found strong differences in behavior and activity of Geometric Tortoises between seasons, and effects of weather, individuals, and sex. High activity was consistent with mild weather during autumn and spring. However, daily temperatures limited female movements on cool autumn days and male movements on warm spring days, a pattern consistent with sexual size dimorphism (large females and small males). Geometric Tortoises exhibited high average daily activity (84%) during both autumn and spring, which is consistent with the mild weather of these seasons.

The tortoises moved significantly further in autumn (average 62.2 m/day) than in spring (40.3 m/day). The longer autumn movements likely help them find new food plants stimulated by autumn rains and assist males in finding mates before female ovulation. Males generally displaced further (straight-line distance) than females did in both seasons. Furthermore, male paths were more linear and directional, whereas female paths were more varied and non-directional. Males had a higher displacement-to-distance ratio, potentially to engage with multiple females while avoiding other males. The high activity of females in spring should help them forage and sustain their vitellogenesis, egg production, and nesting in spring.

Environmental temperatures limited movement differently for each sex. In autumn, female movement correlated positively with ground temperature (moving more on warmer days). In spring, male movement correlated inversely with ground temperature, moving less as it got hotter, suggesting they were thermally challenged by solar radiation. Tortoises had higher body condition indices in spring than in autumn; however, activity and distance moved did not directly correlate with an individual's body size or condition (Henen et al. 2017).

Geometric Tortoises seek refuge mainly under shrubs, grasses and restios. At higher temperatures, tortoises, particularly males, use denser refuges with better cover than during cooler conditions. Females prefer to hide under shrubs when temperatures are high (van Bloemestein 2005). During the hot and dry season, *P. geometricus* takes refuge in slightly damper microhabitats, i.e., low-lying sites with short, dense restio and shrub cover. Geometric Tortoises do not dig their own burrows but occasionally use the burrows of other animals as refugia, or half-bury themselves in sandy patches under shrubs (Baard and Henen, pers. obs.).

Refugia used in autumn were generally larger in volume but less dense than those used in spring. Grass use for refugia was high in autumn (particularly by males), while shrub use was high in spring (particularly by females). In spring, males utilized denser refugia than they did in autumn and denser refugia than females used in spring. This behavior likely serves to alleviate thermal stress during the warmer spring days. Geometric tortoises

rarely reused the same refuge on consecutive nights (only 1% reuse in autumn and 6% in spring). This frequent switching of shelters is considered a predator avoidance mechanism (Henen et al. 2017).

Home Range and Use of Space. — Hofmeyr et al. (2012) reported that the annual space used by *P. geometricus* varies greatly between individuals, and home ranges vary from 1.02 to 44.85 hectares. This study recommended a 95% fixed kernel (FK95) estimate for conservation planning purposes, with a recorded median home range of 5.48 ha. Home range cores (represented by 50% kernel estimates) generally comprise 9–25% of the total annual space use. Females, the larger sex, have significantly larger home ranges and mean daily displacements than males, with a positive relationship between body size and home range for females; that is, larger females require more space, likely due to higher nutritional needs for egg production. In contrast, male home range size is not influenced by body size.

Movement and space use are lowest during the wet season, likely due to low winter temperatures limiting activity and there being an abundance of food, which reduces the need to travel far for nutrients. Both sexes increased displacement during the dry season, possibly because warmer temperatures allow for more activity or because food becomes scarcer, requiring further travel. Females maintain high space use throughout most of the year, including the nesting season. Males displace further during the non-nesting season than the nesting season—a behavior attributed to males seeking mating opportunities outside the nesting season.

While the type of habitat (mature renosterveld, burnt renosterveld, or old fallow wheat fields) did not significantly change the size of the home range, it affected its structure. Home ranges in fallow fields were more elongated and showed higher overlap than those in natural vegetation. There was a high mean home range overlap (59%), arguing against territoriality and because male overlap was biased toward females, it suggests that males position themselves to optimize encounters with mates. This may explain why Geometric Tortoise males are not known to show aggression towards or fight with other males (Baard, pers. obs.).

Geometric Tortoise home range size, structure, and overlap have conservation planning implications. Hofmeyr et al. (2012) highlighted that remaining existing habitat fragments and some reserves are often smaller than the maximum home range size of a single tortoise. Conservation planning for the survival of viable populations over the next generation (possibly ca. 24–29 yrs), must focus on securing large, interconnected and relatively pristine habitat areas and corridors that allow for year-round activities.

Closely related to population status, home-range size, behavior and activity, and the use of space and

habitat by cryptic species such as *P. geometricus*, is the reliable estimation of population size, which is essential for the conservation of rare and cryptic species. However, visual surveys often underestimate abundance because not all individuals present are detected. The Geometric Tortoise occurs in fragmented renosterveld habitats, where dense vegetation and cryptic coloration may reduce detectability.

Gardner et al. (1999) quantified detection probabilities for Geometric Tortoises in the J.N. Briers-Louw Contract Nature Reserve under field survey conditions and evaluated the effects of habitat structure, observer experience, and tortoise size on census accuracy. Life-sized plaster models representing adult females, adult males, and juveniles were randomly distributed in both open and dense renosterveld vegetation and searched for by experienced and inexperienced observers, respectively, using standard census techniques. Overall detection probabilities under realistic group-search conditions were low, averaging approximately 0.60 in open habitat and 0.57 in dense habitat, indicating that about 40–43% of tortoises present were not detected during surveys. Detectability varied markedly among size classes, with adult females exhibiting the highest detection probabilities (0.88–0.92), followed by adult males (0.50–0.63), while juveniles were the least detectable (0.40–0.43). Experienced observers consistently achieved higher detection rates than inexperienced observers, and different observers frequently detected different individuals, demonstrating the value of multiple-observer surveys. Application of detection-corrected estimates substantially increased population density estimates relative to uncorrected census counts. These results demonstrate that raw counts considerably underestimate true abundance and highlight the importance of incorporating detection probability into monitoring programs.

Growth and Longevity. — By analyzing capture-recapture data, Baard (1995a) established that Geometric Tortoises typically experience rapid initial growth that slows significantly as they reach adult size. As summarized above, there is distinct sexual dimorphism, and females are substantially larger and heavier than males, potentially to enhance female reproductive success (e.g., egg, clutch, and hatchling size). The growth pattern follows a typical chelonian trajectory, where annual growth rate is negatively related to body size.

Hatchlings and juveniles exhibit high growth rates to reach a size that likely reduces their vulnerability to predation. This rapid development continues until they reach approximately 90 mm SCL, when growth rates slow. The mean $\pm$ SD SCL for hatchlings is 28.1 $\pm$ 1.0 mm, and juveniles and sub-adults smaller than 90 mm CL grow at an average rate of 10.5 $\pm$ 8.3 mm/yr (Baard 1995a).

Upon reaching a size greater than 90 mm SCL, growth slows considerably. Males grow on average 1.7 $\pm$ 1.9 mm/

yr, while females grow 1.6 ± 1.2 mm/yr. Based on the von Bertalanffy growth model (Fabens 1965), the theoretical maximum size is 116.8 mm for males and 133.2 mm for females (Baard 1995a). These sizes correspond closely with the mean sizes of the 20 largest males (116.2 ± 3.7 mm) and females (134.8 ± 3.0 mm), respectively. While the von Bertalanffy growth curve model (Baard 1995a) provides a good mathematical description of this biological process, it tends to underestimate the body sizes of the largest individuals in the population (see Size and Weight). This discrepancy suggests that while the model captures the general population trend, environmental factors and individual variation account for specimens that exceed the predicted mean asymptotic size.

Baard (1995a) estimated that males reach sexual maturity at 5 to 6 years (5.3–5.9), corresponding to the mean size of the smallest 10 individuals classified as males (88.4 ± 1.9 mm SCL $\pm$ SD) and the development of secondary sexual characteristics (e.g., plastron concavity and tail length) at approximately 90 mm SCL (Baard 1990, 1995a). While definitive data were limited, the smallest egg-bearing female measured 120 mm SCL, which the model suggests is approximately 17 years of age. However, additional data (Hofmeyr and Henen, unpubl. data) suggest that males may reach sexual maturity at approximately 8–10 years, and females at approximately 11–13 years of age. While males reach maturity relatively quickly, females continue growing to a larger size over a longer duration.

Baard (1995a) suggested that Geometric Tortoises may reach ages of approximately 30 yrs, and Goode et al. (2012) estimated life span at between 30 and 40 yrs. Based on the equations for estimating generation time and longevity developed by Iverson (2024), and if based on an age of ca. 5.5 yrs at sexual maturity (Baard 1995a), longevity in *P. geometricus* would be ca. 53 yrs, with a generation time of ca. 13.3 yrs, but if sexual maturity occurs at ca. 11–13 yrs as suggested by Hofmeyr and Henen (unpubl. data), the calculated longevity could be as long as ca. 68–74 yrs, with a generation time of ca. 24–29 yrs.

Baard (1995a) proposed that vertebral scute growth rings are unreliable for aging Geometric Tortoises beyond the early years. In juvenile tortoises, up to six rings can form annually, but as they mature, shell wear and slower growth diminish the accuracy of ring counts. Therefore, size-age models are preferred over ring counts for estimating the age of *P. geometricus* and other South African tortoise populations, especially in regions where annual brumation is uncommon. This is particularly relevant in temperate areas like the Western Cape, where mild winters influence growth patterns. Relying on size metrics provides a more consistent and dependable method for age estimation in these environments.

Reproduction. — *Psammobates geometricus* females attain sexual maturity relatively slowly. Mating is pre-

dominantly observed in spring (September–November) and oviposition typically occurs from winter to early summer (July–December) with ca. 1–3 clutches laid per year (Henen and Hofmeyr, unpubl. data). Clutch size ranges from 1–5 brittle-shelled eggs, most commonly 2–4, and clutch size generally increases with female age and body size. Extended droughts may suppress reproduction and cause females to skip oviposition in adverse years (Henen and Hofmeyr, unpubl. data), although Baard (1990) reported that up to five clutches may be laid in a year. Eggs average 28.4×23.8 mm and 10.4 g (Rudner 1991; Iverson et al. 2025). Estimates of egg sizes from x-rays (28.25×24.25 mm) (Baard 1990; Hofmeyr et al. 2005) suggest an egg mass of 9.3 to 9.6 g, and relative clutch mass of 5.9 to 6.2% of body mass, similar to that of congeners (Hofmeyr et al. 2005; Iverson et al. 2025).

Nests are excavated to a depth of approximately 8 cm, frequently at the base of shrubs and in north-facing, sunlit, and well-drained microsites (Baard 1990). Incubation lasts 4–8 months, with hatchling emergence concentrated in late April to early May, synchronizing emergence with the onset of winter rains that soften the soil, stimulate herbaceous plant growth and reduce wildfire risk. Female reproductive traits—relatively small eggs and comparatively high clutch size among Southern African tortoises—are consistent with adaptation to mesic conditions (Hofmeyr et al. 2005, 2012, 2014).

Despite regular nesting, hatchling recruitment and survival is low. Nest predation and high early mortality result in low recruitment to the juvenile cohort (Hofmeyr and Baard 2018). The combination of slow maturation, low juvenile recruitment and high adult longevity yields a long generation time, estimated at 30–40 years (Baard 1995a; Goode et al. 2012). This may be an over-estimation, since Iverson (2024) calculated *P. geometricus* generation times as either ca. 13.3 yrs if using maturity estimates of 5.5 yrs from Baard (1995a), versus 24–29 yrs if using maturity estimates of 11–13 yrs from Hofmeyr and Henen (unpubl. data).

These life-history characteristics render Geometric Tortoise populations slow to recover from catastrophic declines and particularly vulnerable to increased juvenile mortality or reduced reproductive output. All three, catastrophic declines, high juvenile mortality, and reduced reproduction, may often coincide (e.g., with catastrophic fires), combining and exacerbating these effects on population declines and extending recovery times.

The species' dependence on seasonal rainfall for successful emergence and early-life survival, together with its low fecundity and protracted maturation, indicate high sensitivity to climatic and anthropogenic change, and alterations in rainfall seasonality or reductions in precipitation impacts recruitment and population survival significantly.

Body Condition and Hematology. — Hofmeyr et al. (2017b) and Walton and Hofmeyr (2017) provided base-

line physiological data on *P. geometricus* body condition and erythrocyte morphology, setting robust physiological reference values to assess individual and population health. They investigated seasonal, sex, and age-related variation in body condition, hematological indices, and erythrocyte morphology using individuals sampled across four seasons (spring 2000–winter 2001).

Body condition indices showed limited correlation with hematological measures but were inversely related to blood urea nitrogen, highlighting dehydration stress during autumn, the end of the dry season. Males exhibited elevated packed cell volume, hemoglobin (Hb) and red blood cell counts in summer and autumn, reflecting the energetic costs of mate-searching movements, while females displayed higher Hb than juvenile Hb, consistent with females' reproductive demands. Winter was marked by reduced Hb levels, coinciding with low temperatures and suppressed activity.

Erythrocyte morphology revealed seasonal shifts: immature cells predominated in winter and spring, indicating increased erythropoiesis, whereas summer and autumn were characterized by mature and senescent cells, with morphological adaptations (smaller, elongated erythrocytes) enhancing oxygen exchange under high metabolic demand. Together, these findings demonstrated how intrinsic (sex, age) and extrinsic (seasonal climate, resource availability) factors shape tortoise physiology. The reference intervals and established morphological profiles provide essential diagnostic tools for conservation management, enabling more effective monitoring of population health under ongoing habitat fragmentation and environmental stress.

In addition and related to tortoise body condition indices and physiological health, Horak et al. (2006) identified five species of ticks infecting *P. geometricus*, namely *Hyalomma truncatum*, *Rhipicephalus gertrudae*, *Amblyomma marmoreum*, *A. sylvaticum*, and *Ornithodoros compactus*. With *A. marmoreum* the most prevalent on *P. geometricus* (Horak et al. 2006), Mofokeng et al. (2021) warned that heavy infestations of *Amblyomma* ticks in southern African tortoises can result in clinically significant anemia, reduced body condition, and impaired physiological performance, while also facilitating transmission of *Hepatozoon fitzsimonsi* and related haemogregarines. Anemia is considered the principal immediate physiological threat, whereas hemoparasitism represents the primary infectious disease risk.

Henen et al. (2013) presented a telling case study in how conservation biology intersects with forensic science. The January 2001 confiscation of 16 *C. angulata*, 23 *P. geometricus*, and 15 *H. areolatus* by conservation authorities in KwaZulu–Natal Province provided a rare opportunity to evaluate the physiological toll of illegal trade on both endangered and common tortoise species. Henen et al. (2013) approached it by comparing the body

condition indices and hematological parameters of the confiscated tortoises against wild reference populations of the same species and time period to determine whether the elapsed time between poaching and confiscation had measurable negative impacts on tortoise health.

Confiscated tortoises showed poorer body condition and altered blood values compared to wild counterparts and these differences suggested stress, malnutrition, and dehydration linked to captivity and transport. Patterns of rapid water uptake on rehydration and the suite of clinical markers were consistent with chronic desiccation and starvation occurring over weeks to months. Multivariate discriminant models correctly classified animals as wild or confiscated with 80–90% accuracy and revealed that species and sex effects on health markers often exceeded the effect of capture status, indicating the necessity of sex- and species-specific reference ranges. These rapid, portable assessment methods provided timely forensic evidence that contributed to conservation officers arguing extenuating circumstances and pursuing successful prosecution and large fines under regional conservation laws.

Henen et al. (2013) recommended establishment and expansion of baseline reference datasets across both sexes, seasons, and populations, validation of discriminant functions on independent samples, and incorporation of these protocols into wildlife forensic and rehabilitation workflows. Given the significantly negative impact of international illegal trade in reptiles (Auliya et al. 2016), results from studies like these will provide quantitative evidence that illegal trade compromises tortoise health, thereby strengthening conservation authorities' ability to argue cases successfully in court.

Engelbrecht (1995) demonstrated that the water requirements of *P. geometricus* appear to be met largely through dietary sources. Low evaporative and fecal water losses, combined with seasonal regulation of sodium excretion, contribute to efficient water conservation. During dry periods, increased sodium and water reabsorption by the kidneys reduces fluid loss, while nitrogen excretion patterns shift in response to changing environmental conditions. These mechanisms enable the species to maintain water and electrolyte balance despite pronounced seasonal fluctuations in water availability. Whether this would still protect the species in cases of severe drought caused by climate change is unknown.

Diet. — Early foundational research by Baard (1990) through visual observation and fecal analysis identified 24 genera or species of plants in the diet of *P. geometricus*, including among others, *Aspalathus* sp., *Oxalis* sp., *Pelargonium tristis*, *Ehrharta calycina*, *Eragrostis curvula*, *Heteropogon contortus*, and *Themeda triandra*. However, Baard's findings also highlighted a significant knowledge gap, given that 40% of the plant material examined in feces remained unidentifiable, suggesting the tortoise's

diet is more diverse than initially catalogued. In addition, Engelbrecht (1995) identified two additional plant species, *Babiana stricta* and *Lachenalia* sp., as observed food items.

Balsamo et al. (2004, 2005) and Henen et al. (2005) analyzed 17 common plant species, including nine known food plants and eight non-food species, for nutrient concentrations (crude protein, fiber, lipids, minerals) and biomechanical properties, specifically leaf failure load (the force required to break a leaf) and tensile strength. Field observations by these researchers confirmed the consumption of low-lying grasses previously identified by Baard (1990), such as *Cynodon dactylon* and *Briza maxima*, and expanded the known dietary database by identifying two new species of monocotyledonous geophytes: *Cyanella hyacinthoides* and *Lachenalia contaminata*. Nutritional analysis revealed significant disparities between food and non-food items.

Food plants were characterized by higher levels of soluble carbohydrates, and significantly lower levels of acid detergent fiber (ADF) and lipids, compared to non-food species. High soluble carbohydrates likely enhance palatability and are easily assimilated, while high ADF and lipids (often associated with unpalatable oils or waxes) may act as deterrents. In the phosphorus-poor Cape Floristic Region, food plants exhibited higher phosphorus concentrations, particularly in grass species, and showed significantly higher iron concentrations (Henen et al. 2005).

From a biomechanical perspective, diet selectivity is strongly influenced by the physical effort required for consumption. Non-food species possessed significantly higher leaf failure loads and tensile strength than food plants. Leaf failure load correlated inversely with phosphorus and protein content. Furthermore, neutral detergent fiber (NDF) was the primary predictor of tensile strength; species with high NDF, such as *Aristida diffusa*, are avoided because they are too tough to break and consume.

These findings suggest that *P. geometricus* selects food based on an integration of high nutritional rewards (soluble carbohydrates and phosphorus) and low biomechanical costs (lower tensile strength). The inclusion of newly identified geophytes like *L. contaminata*—which provides high water content, minerals, and low fiber—underscores the importance of diverse flora within the renosterveld. Understanding these critical links is essential for the effective management and protection of the remaining renosterveld fragments to ensure not only the survival of the Geometric Tortoise but other species as well (Balsamo et al. 2004, 2005; Henen et al. 2005; Hofmeyr et al. 2014).

Population Status. — Land transformation for agriculture and viticulture within the historic range of the Geometric Tortoise has been extensive, destructive, and significantly detrimental to the species' presence in

remaining natural habitats, threatening its survival and ecological stability (Baard 1989b). Wheat farming, involving the physical clearing of pristine natural land by ploughing, in the greater Swartland region (major historic stronghold for *P. geometricus*) dates back to the mid-1600s, soon after European settlers arrived at the Cape of Good Hope. The Mediterranean climate (wet winters, dry summers) and fertile, shale-derived soils made it ideal for grain cultivation. Additionally, the Swartland wine grape industry began in the late 1600s, also by early European settlers at the Cape, only gaining global recognition in the late 1990s when pioneering winemakers transformed the region. The Breede River and Ceres valleys, meanwhile, developed into major viticultural and deciduous fruit hubs during the 18th and 19th centuries, becoming two of South Africa's largest fruit and wine-producing regions.

Reinhold Rau (Fig. 12), then a newly-appointed taxidermist at the South African Museum in Cape Town (now the Iziko South African Museum), responded to a request in 1965 by Robert Mertens at the Senckenberg Museum in Frankfurt am Main to investigate the "rediscovery" of the Geometric Tortoise described by Eglis (1965); the species was thought to have gone extinct at the time. Finding only a single preserved specimen in the South African Museum's herpetological collection, Rau began to examine its distribution in the Swartland in January 1965.

Earlier theories had attributed the species' decline to Indigenous people's use of tortoise shells for containers, but Rau (1969) argued instead that modern agricultural expansion posed the primary threat. After finding farms where Geometric Tortoises were present, he reported that the species was confined to acidic, sandy lowlands known locally as the "Sauerfeld" [English = "sour veld"; Afrikaans = "suurveld," hence the colloquial name "*suurpootjie*" for the tortoise]. Here the soils were naturally acidic and low in nutrients, and the term was historically used by landowners to describe areas where the grass tasted "sour" to livestock, especially during the cold season. Rau recognized that the "suurveld" was rapidly being converted to farmland for grain and vegetables.

In addition to habitat loss, Rau (1969) noted threats from seasonal brush fires and predation by corvids such as the Pied Crow, *Corvus albus*, or White-necked Raven, *Corvus albicollis*. He also recorded testimony from older farmers who recalled that the tortoise was once common in their youth, but absent for many years, underscoring its rarity and severe decline.

Rau's work (1969, 1971, 1976) came when herpetological collections were sparse, and the rediscovery of a presumed extinct species carried significant weight for conservation biology in South Africa. Recording recollections of finding fewer and fewer "*suurpootjies*" by older farmers placed the tortoise's decline within living memory, making its rarity more tangible and grounding



Figure 12. Reinhold Rau at the Eenzaamheid Provincial Nature Reserve, ca. 1972. Photo published by Juvik (1972), photographer unknown.

the tortoise in both landscape and culture. His identification of agriculture, fire, and predation showed the layered pressures on the species for the first time.

Since approximately 1972, following the establishment of the first known formally designated area for the protection of a viable Geometric Tortoise population on the farm Eenzaamheid in the Paarl District (Juvik 1972), and up to approximately 1985, a total of 34 cited and inferred populations of Geometric Tortoises were known (Greig and Boycott 1977; Baard 1990). Intensive desktop research, field surveys and interviews with landowners during 1985–1991 added another 33 sites, either new or of possible occurrence. All 67 localities were surveyed by Baard and his team in the mid-1980s and early 1990s and the presence of Geometric Tortoises was documented for 31 of the 67 sites (Baard 1993). This was more recently followed by CapeNature surveys of all known and documented sites in 2009–2010 and during the last decade.

In an interview with CapeNature in March 2026 and based on surveys conducted over the past five years, including the pioneering conservation detection dog project initiated in 2012 (Hudson et al. 2020) (Fig. 13), it was agreed that at least 28 sites currently support Geometric Tortoise populations of varying sizes in the Western Cape Province. The list and details of these sites are filed with the Landscape Conservation Intelligence Manager of CapeNature's Central Landscape in Stellenbosch (A. Duffell-Canham, pers. comm.).

Only the Voëlvllei Provincial Nature Reserve and the Kasteelkloof portion of the Waterval Protected Area Complex are on state or public land, while the rest of the sites are on private or corporate land. Two sites, Elandsberg and J.N. Briers-Louw Contract Nature Reserves benefit from formal protection through formal biodiversity stewardship agreements with CapeNature.

Specific Population Status. — The status of some former and current populations of Geometric Tortoises is presented below.

- The single specimen of *P. geometricus* photographed by the reserve manager of the Koeberg Nature Reserve (Eskom Power, Koeberg Nuclear Power Station) in January 1997, and identified by Baard, was never followed by subsequent specimens (see Distribution) and it is believed that no viable population persists there.

- In 1990, a single specimen was found in Riverlands Nature Reserve (CapeNature) near Malmesbury. However, subsequent and recent surveys by reserve managers have failed to locate additional individuals during intensive monitoring of threatened plants and animals. This is not surprising because the nature reserve conserves a major proportion of threatened Atlantis Sand Plain Fynbos vegetation that is unlikely to support a viable Geometric Tortoise population (Baard, pers. obs.).

- The Harmony Flats Nature Reserve (CapeNature), established in 1984 on a 9-ha Lourens River Shale Renosterveld patch between the towns of Strand and Gordon's Bay, and approximately 1 km from the False Bay coastline, was surrounded by rapid urban development (Lwandle and Gustrouw) and always at risk. Regular monitoring revealed that at least four fires between 1986 and 1993 reduced the population from just more than 50 individuals to fewer than 10. Population modelling predicted extinction by 1998–2000 (Baard 1995c), which indeed occurred and the population is deemed extirpated. Shortly after 2000, the reserve was abolished and transferred to the City of Cape Town's Spatial Planning and Environment Directorate to be managed as an urban park.

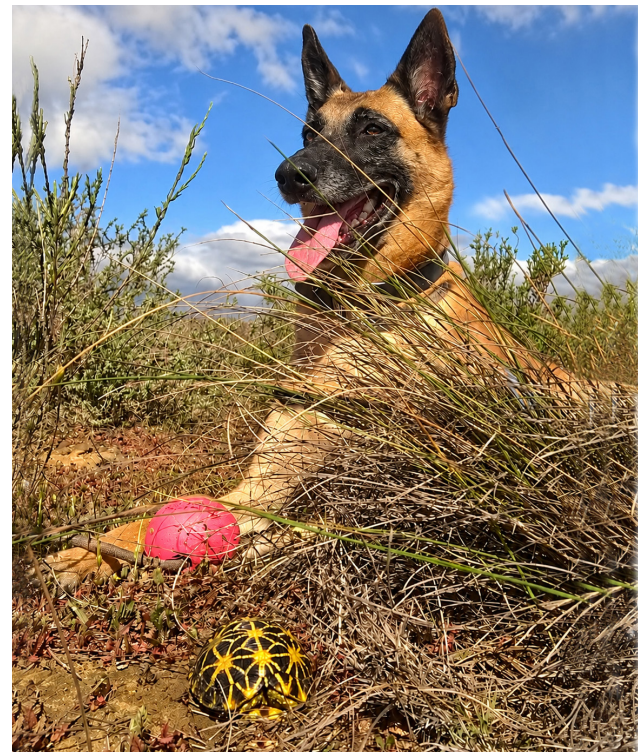


Figure 13. Professionally trained conservation detection dog guarding a Geometric Tortoise found during surveillance operations. Photo by Vicki Hudson.

- The J.N. Briers-Louw Contract Nature Reserve (Biodiversity Stewardship Contract Nature Reserve), established in 1972 on the farm Eenzaamheid in Paarl District, as the first reptile-focused reserve in Africa, initially reported promising numbers. Greig (1984) recorded 80 individuals in 1976, 170 by 1980, and 130 in 1984. However, these figures were inflated due to translocations: following Rau's (1969, 1971) rediscovery of the species on nearby farms, many tortoises were relocated to the reserve by the Cape Department of Nature Conservation (now CapeNature) between 1976 and 1982. Recent surveys estimate ≤ 20 individuals remain (CapeNature, unpubl. data).

- Two provincial reserves, Hartebeest Rivier and Romans Rivier (CapeNature), were abolished as provincial nature reserves in the late 1980s. Both contained severely depleted, non-viable remnants of Geometric Tortoise populations. However, each may still have a small number (≤ 20) of individuals.

- The Voëlvlei Nature Reserve and "Kasteelkloof Nature Area," listed by Baard (1993) and situated immediately to the north of the Elandsberg Contract Nature Reserve, are technically part of the Western Cape provincial Waterval Protected Area Complex, managed by CapeNature. The Geometric Tortoise population on the Voëlvlei portion has been monitored since ca. 1994 by CapeNature, with 83 individual Geometric Tortoises marked and released on the nature reserve in ca. two years (van der Walt, in litt., 1996) but numbers have continued to decline due to wildfires and serious habitat damage by feral pigs (see Threats). The current number of tortoises is estimated at ≤ 50 individuals.

- Two additional nature reserves have been under negotiation for several years, namely a portion of the Perdefontein farm near Ceres (Ceres Valley), and a portion of a private farm near Worcester (Upper Breede River Valley). The Ceres Valley was transformed for viticulture many years ago, resulting in the loss of much of its original habitat (Baard, pers. obs.), but at least four sites with ≤ 25 individuals each occur within the Ceres Valley (ca. ≤ 100 total individuals).

- Eberle (2003) surveyed two remnants of renosterveld on a portion of a private farm near Worcester (Upper Breede River Valley), situated along and on opposite sides of the N1 highway between Du Toitskloof and Worcester. The highway was identified as a major barrier to movement between these sites and, consequently, for the resident *P. geometricus* population. To mitigate the adverse impacts of the highway on this population, the study recommended the construction of wildlife underpasses, installation of tortoise-proof fencing, and habitat restoration to reduce fragmentation, minimize mortality, and enhance the population's long-term viability. A major and significant step forward for Geometric Tortoise conservation was when 485 ha of virgin renosterveld on this private farm near

Worcester—always regarded as the densest Geometric Tortoise population—was purchased by the USA-based Turtle Conservancy and managed by the Southern African Tortoise Conservation Trust (SATCT) (Kiestler et al. 2023), eventually joined in partnership with the South African-based Mapula Trust. Mark-recapture surveys, supplemented by conservation detection dog surveys, currently place the tortoise population there at between 800 and 1,200 individuals (Kiestler et al. 2023). The status of this land parcel remains as a private nature reserve with the intention to manage it as part of the metapopulation, and more recent land purchases have increased the size of the reserve to 526 ha (A. Naudé and E.V. Goode, pers. comm.).

- Finally, the Geometric Tortoise population of the Elandsberg Contract Nature Reserve—previously regarded as the last, major stronghold for the species and saved from government expropriation in the 1970s by the late owner, Dale Parker—has experienced a steady decline in numbers since the first recorded big wildfires in March 1982 and February 1988, as follows:

1. Greig and de Villiers (1982) were the first to estimate this population at approximately 2,000 individuals.

2. Using mark-recapture data, Baard (1990, 1992b) estimated the population at approximately 2,000–3,400 individuals in an approximately 1000 ha low-lying portion of the reserve. The estimate was based on a total of 232 individual tortoises (55 males, 58 females and 119 indeterminates—hatchlings, juveniles, and subadults) collected, marked, released, and recaptured from four 4 ha (16 ha total) permanent plots over two years (1987–1988) and eight seasons (370 observations; 86 male, 104 female, and 180 indeterminate records).

3. Two devastating wildfires in 1999 and 2012, and concomitant mortalities among juveniles and adults, reduced the population to a suspected ≤ 800 individuals (Goode et al. 2012; Hofmeyr, pers. comm.).

4. In January 2024, a runaway wildfire caused more mortalities, and it is suspected that the population could currently be down to ≤ 500 individuals (J. Austin, pers. comm.).

CapeNature acknowledges that other small, isolated, and likely non-viable populations may persist in various sites within the agricultural–natural vegetation mosaic of the southwestern Cape. These populations, often consisting of only a few individuals, may likely remain undetected and eventually disappear. To counter this, CapeNature remains committed to revisiting known and potential sites to confirm presence, assess persistence through evidence of recruitment, and monitor population status, ensuring that viable populations are sustained into the future. Some non-viable populations could potentially be used to foster temporary breeding populations or boost mating success.

Since there have been no recent formal population size estimates or surveys of sites on private land, it is

difficult to calculate an approximate total population size for the species.

However, we can estimate and assume that:

1. the Hartebeest Rivier (abolished), Romans Rivier (abolished), Voëlrvlei, and J.N. Briers-Louw Nature Reserves collectively hold ca. ≤ 100 individuals,
2. the SATCT private nature reserve near Worcester has ca. ≤ 1000 individuals,
3. Elandsberg has ca. ≤ 500 individuals (J. Austin, pers. comm.),
4. at least three sites west of the mountains Saron, Gouda Windfarm, and Agter-Groenberg have ca. ≤ 150 total individuals,
- and, further, based on historic visits and surveys,
5. at least four sites with ≤ 25 individuals each occur within the Ceres Valley (ca. ≤ 100 total individuals), and
6. at least four additional sites in the Upper Breede River Valley with ≤ 25 individuals each (ca. ≤ 100 total individuals).

As a result, it stands to reason that there may be a total population of ca. $\leq 2,000$ Geometric Tortoises left in the wild (low to medium confidence).

Threats to Survival. — Human-induced habitat alteration, degradation, and destruction—largely from extensive agricultural development (wine and wheat farming) over the last century—has impacted more than 90% of Geometric Tortoise habitat. Human settlement with associated telecommunication and electrical infrastructure, agriculture including viticulture, invasive alien species (woody and herbaceous), native and invasive predators (corvids, baboons, and honey badgers), overgrazing and trampling by domestic stock, droughts and wildfires (Fig. 14) seriously threaten the survival of remaining Geometric Tortoise populations in remnant habitats. These threats are exacerbated in small, isolated populations that may no longer be viable (Baard 1997; Hofmeyr and Baard 2018; Underhill 2025).

Invasive alien woody plants, predominantly Port Jackson *Acacia saligna* and Coastal Wattle (=“rooikrans”) *Acacia cyclops*, are among the worst invaders in low-lying natural habitats of the Western Cape. Left unchecked, they form dense thickets that outcompete coastal strandveld, renosterveld, alluvium, and sand plain fynbos, and other lowland habitats. These thickets create an understory poor in native species used by tortoises for shelter and forage, and they establish persistent seed banks that promote aggressive regrowth unless follow-up clearing occurs. Manual clearing is effective only when initial removal is followed by at least two to three follow-up treatments. The release of natural biocontrol agents (insects, fungi) as part of integrated control programs has had varied success.

Invasive alien herbaceous plants (primarily alien grass and weed species) continue to invade natural habitats mostly unnoticed from surrounding wheatfields and can cause monocultures if left unchecked, e.g., *Briza minor*



Figure 14. Post-wildfire regeneration of Geometric Tortoise habitat. *Top:* Freshly burnt veld. *Middle:* Approximately 3–4 years post-fire. *Bottom:* Approximately 14 years post-fire. Photos by Ernst H.W. Baard.

and *B. maxima* at the J.N. Briers-Louw and Elandsberg Contract Nature Reserves (Baard, pers. obs.). The indiscriminate use of agricultural insecticides and herbicides, administered by crop-spraying aircraft, causes much drift into otherwise natural pockets and sites with natural renosterveld and the impact on tortoise populations is unknown (Baard, pers. obs.).

Hyper-predation by corvids is geographically widespread and can be locally severe, often facilitated by anthropogenic subsidies (food, water, perching, nesting, and roosting sites) and linear infrastructure (roads, power lines). These features commonly provide nesting opportunities for corvids and increase predation pressure on



Figure 15. Adult *Psammobates geometricus* burned in wildfire sweeping through their renosterveld habitat. Photos by Alwyn Naudé.

chelonians (see review by Moldowan 2023). Underhill (2025) attributed the expansion of Pied Crows, *Corvus albus*, into the treeless Karoo ecosystem of South Africa primarily to the provision of artificial nest sites (utility poles for telephone and electricity, windpumps), rather than to increased food availability or climate change. Telephone lines to rural farms were widely and extensively installed from the 1920s and windpumps peaked mid-20th century. These structures pre-dated the main observed range expansion of corvids but later provided nesting opportunities that corvids exploited. The Pied Crow is aggressively replacing other native corvids in mixed agricultural–fynbos habitat across the range of *P. geometricus* and causes considerable mortality in other tortoise species (Juvik and Hofmeyr 2015), notably *C. angulata* (Baard 1995d; Fincham and Lambrechts 2014; Moldowan 2023; Baard, Hofmeyr, and Henen, pers. obs.).

Other potential predators, such as White-necked Ravens, *Corvus albicollis*, and Black-backed Jackals, *Lupulella mesomelas*, also occur in Geometric Tortoise habitat, while Chacma Baboons, *Papio ursinus*, and Honey Badgers, *Mellivora capensis*, have been observed preying on tortoises (J. Austin, Baard, pers. obs.). Feral pigs, *Sus scrofa* x *S. domesticus*, are not suspected to be primary predators, but their presence coincides with significant and extensive physical damage and alteration of pristine renosterveld in the Voëlvlei Dam / Voëlvlei Nature Reserve / Elandsberg Nature Reserve region (B. Wooding, pers. obs.). Lethal control programs have had mixed success. After a wildfire in 2012 at Elandsberg Nature Reserve, baboons depredated rescued Geometric Tortoises that were kept in holding pens, killing and eating the tortoises, and now occur in larger troops on protected lands adjacent to the reserve (M. Gregor, B. Wooding, pers. obs.).

Increased stocking of cattle in small renosterveld sites is believed to have led to trampling of juvenile and adult Geometric Tortoises, posing a risk of extirpating small, vulnerable populations (Baard, Hofmeyr, pers. obs.). Although infrequent, illegal collection for subsistence consumption remains a potential threat.

For several decades, irrigation canals crossing the Ceres Valley’s remaining tortoise habitat have acted as pitfalls, trapping and killing *P. geometricus* and other tortoise species, *C. angulata* and *H. areolatus*, in significant numbers (Juvik et al. 2014).

With two significant poaching events involving Geometric Tortoises successfully detected by law enforcement and conservation authorities—one in 2001 (23 specimens) (Henen et al. 2013) and another in 2026 (16 specimens) (Baard, pers. obs.)—the illegal removal of individuals from the wild appears relatively infrequent and does not apparently currently threaten the meta-population. However, the removal of these numbers from small, fragmented populations would be catastrophic, pushing them to the brink of extirpation.

Environmental stochasticity—severe droughts, extreme weather events and wildfires, which are characteristic of the Western Cape during hot, dry, and windy summers—will continue to pose extrinsic threats, as experienced over the last 40–50 years (Kiestler et al. 2023). CapeNature has recorded an increasing frequency of wildfires in the Western Cape since 2000 (CapeNature 2025; Kraaij et al. 2026) and the slow recovery of renosterveld habitat after wildfires increases exposure of tortoises to predation and more stochastic events, such as recurrent wildfires (Fig. 15).

Projected climate change scenarios for western South Africa, characterized by warmer and drier conditions (Midgley et al. 2005), are likely to further compromise the already critical conservation status of *P. geometricus*. The survival of remaining fragmented populations will be negatively affected under these conditions (Hofmeyr et al. 2006). Since Loehr (2010) reported that droughts had significant adverse impacts on the body condition, growth, and reproduction of *Chersobius signatus*, it is highly probable that *P. geometricus* will exhibit similar responses.

Accordingly, it is reasonable to expect that the predicted hotter and drier climate in western South Africa will have comparably negative effects on the survival of

threatened species such as *P. geometricus*, *C. signatus*, *C. boulengeri*, and *P. tentorius trimeni* (Tolley et al. 2023b), as well as on the more common *C. angulata* and *H. areolatus*. Severe droughts, prolonged periods of low rainfall, and elevated temperatures can restrict recruitment and hinder the recovery of depleted tortoise populations, reduce juvenile survival, and extend the time required to reach maturity (Berry et al. 2023).

Conservation Measures Taken. — *Psammobates geometricus* has been listed as Critically Endangered on the IUCN Red List since 2015 (Hofmeyr and Baard 2015, 2018), having been nationally listed in South Africa as Critically Endangered since 2014 (Baard and Hofmeyr 2014; Hofmeyr et al. 2014; Hofmeyr and Baard 2023). It was previously assessed as Endangered on the IUCN Red List in 1996 (TFTSG in Baillie and Groombridge 1996).

It has been included in CITES Appendix I since 1975 (Baard 1989b), prohibiting all forms of commercial international trade. In South Africa, the species is protected under the National Environmental Management: Biodiversity Act 10 of 2004 as Endangered, and provincially under the Western Cape Nature Conservation Ordinance 19 of 1974 as Endangered. More recently, it was listed as Critically Endangered under the Western Cape Biodiversity Act 6 of 2021. It has been listed as Endangered by the U.S. Endangered Species Act since 1976.

The species has also been consistently treated and listed as threatened—either Endangered or Critically Endangered—by McLachlan (1978), Greig and de Villiers (1982), de Villiers (1985), Baard (1988, 1989a,b,c, 1992c), Baard and Hofmeyr (2014), Hofmeyr and Baard (2015, 2018, 2023), and Rhodin et al. (2018). It has consistently been included near the top of the lists of the Top 25+ most globally endangered freshwater turtles and tortoises by the Turtle Conservation Fund (TCF) and the Turtle Conservation Coalition (TCC) since 2003 (TCF 2003; TCC 2011, 2018, 2025).

Populations occur in two state and two contract nature reserves (see Population Status). However, catastrophic wildfires have repeatedly impacted these reserves, notably at Voëlvlei Nature Reserve and the Elandsberg Contract Nature Reserve in January 2012 and again in 2024. These events prompted the implementation of fire-prevention measures, including early warning systems and the clearing and maintenance of firebreaks. CapeNature, the Western Cape provincial conservation agency, produces annual fire-season maps identifying biodiversity “hotspots”—areas at risk of biodiversity loss due to frequent fires or where priority species are present. The Elandsberg Nature Reserve is consistently flagged as one such hotspot.

Formal conservation planning began with strategies developed by Baard (1994, 1997), which were adopted by reserve managers and shared with private landowners. The Conservation Action Plan (Hofmeyr et al. 2006), later refined by Baard and Hofmeyr (2012), guided

management for several years. In May 2015, CapeNature convened a stakeholder workshop to draft a Biodiversity Management Plan – Species (BMP-S) under the national Biodiversity Act. Although this draft was abandoned due to a very narrow spatial conservation management scope and relatively small stakeholder interest, a more focused Species Conservation Plan was prepared recently and is under review (A. Duffell-Canham, pers. comm.).

The Geometric Tortoise remains a CapeNature priority species of concern for research and monitoring, and conservation actions are embedded in protected area management plans, with annual surveys assessing vegetation condition and tortoise populations to prioritize habitat protection. Reserves are monitored annually to evaluate population presence, persistence, and stability. CapeNature also pursues habitat protection through its Biodiversity Stewardship Program, engaging private landowners in conservation agreements.

At Elandsberg, management has intensified efforts to reduce habitat damage and predation, including feral pig control, measures to deter Pied Crows, and close monitoring of baboon troops. Following a devastating wildfire in 2012 that killed most tortoises in the largest remaining habitat fragment, an *in-situ* head-starting program was initiated by the University of the Western Cape (Hofmeyr, pers. comm.) in collaboration with Elandsberg management to enhance survival of Geometric Tortoise hatchlings and juveniles. Using predator-proof facilities, radio-tracking, health monitoring, and managed incubation, the program successfully developed protocols for rearing hatchlings past the critically first few vulnerable years and provided practical guidelines for conservation head-starting of South African threatened tortoises (Ferreira 2016; Austin et al. 2019).

Beginning in 2015, the Turtle Conservancy, guided by recommendations from CapeNature, began acquiring remaining tortoise habitat in the Upper Breede River Valley to consolidate land for the protection and conservation of one of the largest surviving Geometric Tortoise populations. To manage this initiative, the Southern African Tortoise Conservation Trust (SATCT) was established, comprising both South African and international trustees, who now own and administer the private nature reserve. The area has since expanded to 526 hectares and supports a geometric tortoise population exceeding 800 individuals (Kiester et al. 2023). Securing this amount of pristine habitat is regarded as a major achievement and significant milestone in Geometric Tortoise conservation management. In 2019, the SATCT partnered with the Mapula Trust, owners of the Elandsberg Contract Nature Reserve, and the two organizations continue to collaborate on the sustainable conservation of the Geometric Tortoise.

Despite these efforts, populations remain scattered and severely fragmented, with ongoing declines in habi-

tat extent and quality. This underscores the urgency of sustained and coordinated conservation action.

Recently, the Geometric Tortoise has been selected as one of the 100 global Critically Endangered species (one of 12 turtle and tortoise species) targeted for special attention and conservation funding by the Phoenix Species Project, a joint US\$ 200 million five-year effort by the Bezos Earth Fund and Re:wild aimed at recovery of targeted species (R.A. Mittermeier, pers. comm.).

Conservation Measures Proposed.—The Geometric Tortoise is on the brink of extinction and is one of the most critically endangered tortoise species in the world (TCF 2003; TCC 2011, 2018, 2025). It matures slowly, produces few offspring, and suffers from critically low recruitment. All life stages are highly vulnerable, preyed upon and restricted by specialized habitat and dietary needs. Suspected reduced genetic variation further undermines its resilience, while climate change threatens to erase what little future remains. Over 90% of its natural renosterveld habitat has already been destroyed and what survives is a shattered, fragmented landscape where small, isolated populations cling to existence. These pockets are perilously exposed to random environmental events that could annihilate them overnight. In such isolation, populations have lost the ability to recover through external recruitment from neighboring populations after catastrophic events such as wildfires.

The combined loss of adult females to wildfires, together with persistently high hatchling and juvenile mortality, predation pressure, and ongoing habitat degradation, has populations in non-viable states and quantifying a minimum viable population size for the species may reveal approximate thresholds for collapse. This creates a dangerous illusion of persistence—populations where only adults are found may appear to survive but, with compromised recruitment, in reality, they are hollowed, fragile, and slipping towards extinction (Lovich et al. 2018).

The message is clear: the Geometric Tortoise will disappear from the wild unless the two remaining large populations, along with several smaller ones, are safeguarded and effectively managed. Conservation interventions must mitigate threats, enhance adult female and first year survival, protect nesting habitats, and facilitate reproductive output and nest success. Targeted measures to reduce egg and hatchling mortality are essential to secure recruitment. These population-level actions must be reinforced by landscape-scale strategies that halt habitat loss, restore degraded habitats, and reconnect fragmented populations. Only through this integrated approach can the survival of the Geometric Tortoise in the wild be assured.

A desired state of conservation should be that all interested and affected parties are committed to the following efforts:

1. ensure the long-term survival of the species in the wild by halting the loss of its Extent of Occurrence through halting habitat loss and increasing suitable habitat;

2. secure the Area of Occupancy by increasing the formal protection of populations and the size and connectivity of suitable habitat;

3. improve population growth and viability through appropriate management; and ultimately,

4. re-introduce populations to suitable habitat where feasible; all of which will require ongoing research, population and habitat monitoring, and conservation management.

Because time is running out, the goals of these conservation efforts should be that by 2031, the two large Geometric Tortoise populations are legally safeguarded, ecologically healthy, show persistence and growth (all size classes: hatchlings/juveniles, subadults, adults), and land managers are equipped to contribute to ensuring the future conservation of the species, while the status and resilience of a number of smaller, viable populations is boosted through continued surveillance, conservation management (invasive alien species and wildfire) and landowner commitment.

The outcomes of these efforts and goals must aim towards answering the question of “what did we achieve?” by accomplishing the following results:

- safeguarded, resilient, and growing Geometric Tortoise populations;

- increased awareness of the plight of the Geometric Tortoise, both within the formal conservation sector and among local landowners and residents;

- improved awareness of threats to the species and identification and implementation of management activities to mitigate threats;

- implementation of effective long-term standardized monitoring and surveillance to inform conservation interventions; and

- effective partnerships between government departments, non-government stakeholders, and local communities.

During 2025, CapeNature prepared a comprehensive Species Conservation Plan, currently under review, aimed at improving the state of conservation through the implementation of these three strategies:

Strategy 1: Reduce (halt) habitat loss and address habitat fragmentation through restoring habitat condition and connectivity where possible, to support viable populations of Geometric Tortoises.

Strategy 2: Implement effective invasive alien species management and fire programs in Geometric Tortoise habitat to abate the negative effect that invasive alien species and inappropriate fire regimes have on Geometric Tortoise populations.

Strategy 3: Inform landowners regarding appropriate land use practices and legal requirements linked to protecting Geometric Tortoises and their associated habitat.

Each strategy targets several objectives that are cross-referenced to processes threatening the persistence of the species in the wild.

CapeNature, the conservation agency responsible for implementing the Species Conservation Plan, and in collaboration with all partners, should secure a short-to-medium term funding stream from appropriate funders to:

- a) implement the strategy in “3-year bite-sized chunks” with specific targets, activities, and outputs,
- b) conduct regular presence/absence and persistence surveys by appropriate means, e.g., detection dog teams,
- c) maintain robust partnership communication with landowners and managers,
- d) help landowners enter the biodiversity stewardship program, by providing legal advice and technical support,
- e) generate awareness, teaching, and capacity-building materials.

Furthermore, CapeNature must sustain sufficient and appropriate internal capability, expertise, and experience needed to implement and drive this strategy.

Captive Husbandry. — While South African policies do not permit private citizens to keep Geometric Tortoises in captivity, at least three historic groups of captive specimens have been documented.

A male Geometric Tortoise, kept since 1970, and a female, acquired in 1975, were maintained in urban garden plots at a residence in Cape Town for more than a decade (Rudner 1991). Their diet consisted of weeds, succulents, fruits, vegetables, and calcium supplements. Growth was modest, with the male reaching a carapace length of 113 mm and the female 137.5 mm. Mating occurred sporadically, and the female produced five clutches: August 1977 (3 eggs), September 1978 (4 eggs), December 1979 (2 eggs), May 1983 (4 eggs), and October 1989 (number of eggs unknown). The eggs were deposited in distinctive boot-shaped chambers. Eggs from the first clutch measured $28.2 \times 27.5 \times 23.9$ mm (mean weight, 10.56 g), $29.0 \times 26.8 \times 23.5$ mm (10.41 g), and $28.0 \times 26.9 \times 23.9$ mm (10.28 g), respectively. No hatching success was recorded from any of the clutches, most likely because of male infertility. After 19 and 14 years in captivity, respectively, both tortoises were transferred to Tygerberg Zoo outside Cape Town for structured breeding efforts (Rudner 1991) (see below).

Between 1980 and 1990, Rear Admiral (Ret.) J. Nortier, a resident of Gordon’s Bay in the Helderberg region, kept several Geometric Tortoises from the Harmony Flats area in his garden. Although egg-laying was reported periodically, no successful hatching was ever recorded (Baard, pers. obs.).

In 1988, CapeNature approved the establishment of an experimental captive-breeding group of Geometric Tortoises at the former Tygerberg Zoopark, situated outside Cape Town within the species’ historical range. Managed by John Spence (curator) and Dave Morgan,

the program aimed to develop husbandry techniques for *P. geometricus* in captivity (Morgan 1992). Between July 1987 and May 1992, a total of 23 tortoises from localities including Harmony Flats Nature Reserve, Eenzaamheid Farm, Ceres, and Cape Town were transferred to the facility under CapeNature authorization. Morgan (1992) reported that 11 tortoises died within the first 18 months due to poor adaptation to captive conditions and the husbandry practices employed at the time. In response, the program was revised in June 1991. A mixed diet of natural and artificial food items was introduced, and behavioral observations, including pre-copulatory behavior, were recorded. Egg-laying was documented on three occasions.

Between 1992 and 1995, a further 17 tortoises were acquired from various sources. Despite these additions, the group had declined to 18 individuals by June 1995, following the loss of 16 animals. The remaining group consisted of seven males, eight females, and three juveniles hatched during November and December 1994 (Harris-Smith 1995). During the following year, Harris-Smith (1996) documented a further 11 mortalities attributed to *Salmonella* infections, intestinal rupture and impaction, liver failure, malnutrition, and hemochromatosis. By June 1996, only 11 tortoises remained: three males, five females, and three juveniles. In June 1997, curator John Spence informed CapeNature that 10 adult tortoises had been lost in two separate theft incidents, leaving only two adult females and three juveniles. Although rebuilding the breeding group was considered, Dale Parker of Elandsberg Private Nature Reserve declined to provide breeding stock because of concerns over declining wild populations. Without replacement animals or a viable breeding nucleus, the Geometric Tortoise Breeding Group was formally terminated.

The Geometric Tortoise head-starting program on the Elandsberg Contract Nature Reserve (Austin et al. 2019) has aimed to increase wild tortoise survival by allowing radio-tagged wild females to lay eggs in a controlled enclosure, collecting all hatchlings, and transferring them to a semi-natural rearing facility (e.g., as for Mojave Desert Tortoises; Nagy et al. 2020). Hatchlings are reared until they reach 80–100 mm SCL, a size at which predation risk is substantially reduced. These subadults are released back into the wild to bolster the free-living population. Practical considerations of the program include conducting rigorous health screening to prevent pathogen transfer; maintaining post-release radio-tracking of a representative sample to assess survival, dispersal, and integration; ensuring release sites offer adequate food, shelter, and low predator pressure, implementing genetic monitoring to track diversity in released cohorts and applying adaptive management—using the results of monitoring to refine rearing duration, release size, and timing.

More than 200 hatchlings have been produced (Austin et al. 2019) which demonstrated an opportunity for

supplementing and bolstering reserve populations and potentially producing additional juvenile tortoises for re-introduction at other viable sites within the historic range. The population of head-started tortoises also bolsters the individual numbers and genetic composition of tortoises remaining to ultimately improve resiliency of populations at remaining robust reserves committed to conservation plans.

The SATCT has indicated that they regard a head-starting program at their property a requirement to safeguard their Geometric Tortoise population and to prepare for possible future re-introduction of the species to viable sites where they have disappeared (Kiestler et al. 2023).

Current Research. — An integrated research program is underway to inform population genetics, multi-year reproductive studies, diet and habitat assessments, niche modelling, demographic monitoring via mark-recapture, and targeted investigations of predation at key reserves (including the Elandsberg contract and SATCT private nature reserves). Genetic analyses will identify appropriate source and recipient populations and quantify inbreeding depression, genetic variation and gene flow; reproductive monitoring will evaluate population replacement capacity and potential climate-driven effects on fecundity and recruitment; diet and habitat studies, together with niche models, will refine site selection by matching nutritional and microhabitat requirements; and mark-recapture analyses will provide robust abundance and demographic rates to set sustainable removal quotas and measure post-release outcomes. Priority research gaps to strengthen translocation success include modelling future habitat suitability under climate scenarios, quantifying seasonal availability and nutritional value of key food species, assessing predator population dynamics and mitigation efficacy, and continued long-term monitoring of donor populations to ensure removals do not compromise source viability.

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