NATIONAL SENIOR CERTIFICATE EXAMINATION
NOVEMBER 2019

LIFE SCIENCES: PAPER II

SOURCE MATERIAL BOOKLET FOR QUESTIONS 1, 2 AND 3

SECTION A

QUESTION 1

Read the information below. Use this information as well as your own knowledge to answer Question 1 in the question paper.

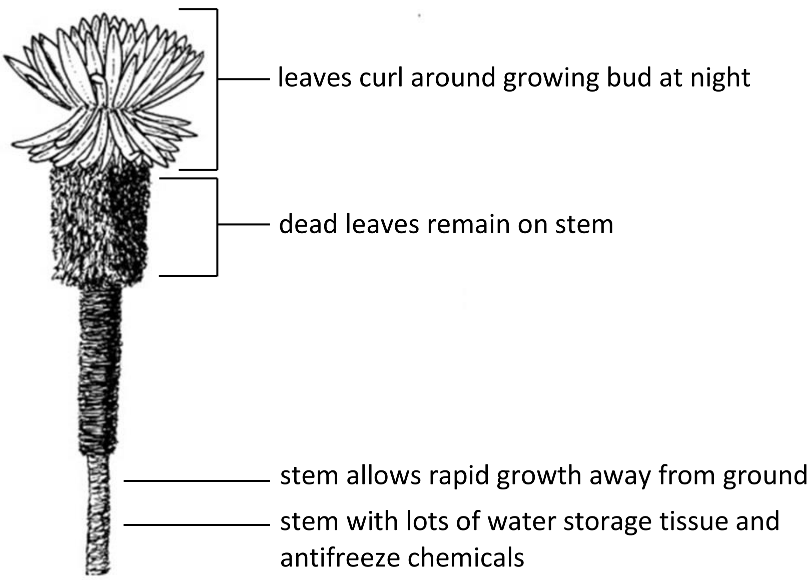
Giant lobelias and groundsels

The amazing forests near the top of Mount Kilimanjaro and other East African mountains are some of the most unusual in the world. Kilimanjaro is the highest mountain in Africa – rising to 5 895 m above sea level. Many of the other East African mountains are almost as tall. At these high altitudes*, the nights are very cold and frosty and the ground often freezes. However, because the mountains are close to the equator, the days are hot. The beautiful forests on these mountains contain alien-looking plants, including **giant groundsels** and **giant lobelias**.

The low-lying areas surrounding the mountains are dry and hot. They are covered with savannah and semi-desert vegetation, where giant lobelias and giant groundsels cannot survive. This is because they are adapted to the particular climate on top of the mountains. Different species of these plants occur along the equator in many parts of the world, always at altitudes ranging from 3 000 to 6 000 m above sea level.

Giant lobelias and giant groundsels are strange-looking plants. They have large woody stems containing lots of water-storage tissue. The large leaves often curl around the growing bud at night and tend to remain on the stem even after they have died. The plants also secrete a natural form of anti-freeze into the water in the stems. The woody stems grow rapidly, ensuring that the rest of the plant is supported far above the cold ground. These traits appear to be adaptations to the nightly frosts, insulating vulnerable tissue and preventing water freezing in the stems. Water can therefore be provided for growth, even when the ground is still frozen in the mornings.

*altitude = height above sea level



[Adapted: <https://ars.els-cdn.com>]

Drawing of a giant groundsel showing growth characteristics

A giant groundsel forest
[Adapted: <www.wondermondo.com>]

A giant lobelia
[Adapted: <https://i.etsystatic.com>]

The various species of giant lobelias occur in Africa as well as in many other high-altitude areas of the world and show an "Out of Africa" origin. All lobelias produce thousands of dust-like, wind-dispersed seeds. For example, the Mount Kenya giant lobelia produces such small seeds that 36 000 of them have a combined mass of only one gram.

Giant lobelias and giant groundsels are **not** closely related even though they share many characteristics in common (for example, large fast-growing woody stems, lots of water-storage tissue and leaves that curl around the bud). Analyses of DNA sequences show that the growth characteristics in these plants have evolved independently many times by convergent evolution. Therefore, similarity in structure is likely to be a poor way to determine relationships between the giant lobelias and giant groundsels.

The five species of giant groundsels all belong to the genus *Dendrosenecio* and occur on the mountains of equatorial East Africa, including Mount Kilimanjaro, Mount Meru and Mount Aberdares as seen in the diagram on page iv.

[Adapted: Antonelli, A. 2009. Have giant lobelias evolved several times independently? Life form shifts and historical biogeography of the cosmopolitan and highly diverse subfamily Lobelioideae (Campanulaceae). *BMC Biology* 7: 82
Adapted: Givnish, T. J. 2010. Giant lobelias arose by convergent evolution. *BMC Biology* 8(1): 3]

Climate change is threatening the survival of these mountain forests. Loss of habitat is expected due to warmer temperatures at these high altitudes. The remaining small isolated patches of forest will also have a reduced level of genetic diversity and could result in a higher risk of extinction of species such as giant groundsels.

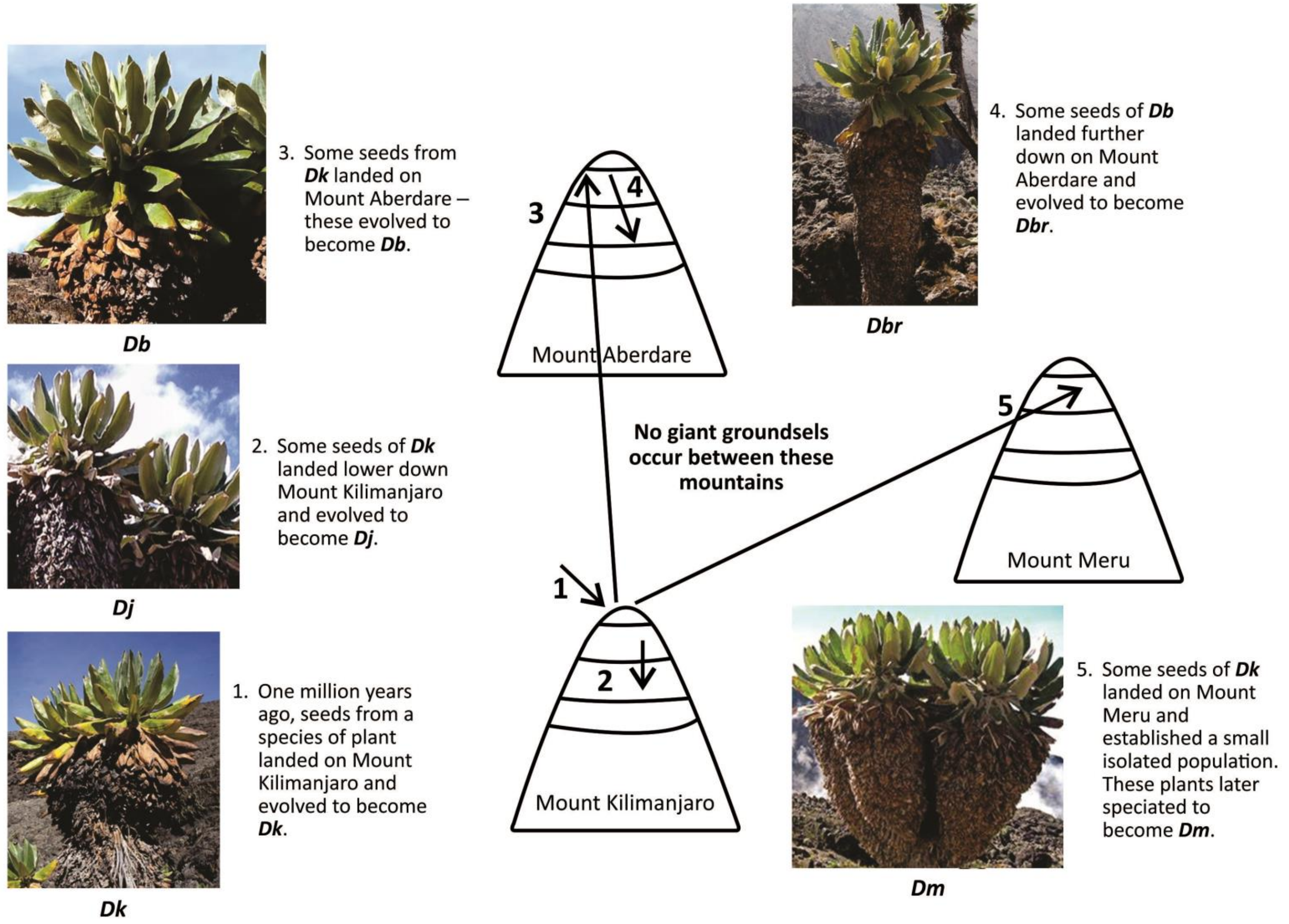
[Adapted: Buytaert, W. et al. 2011. Potential impacts of climate change on the environmental services of humid tropical alpine regions. *Global Ecology and Biogeography* 20: 19–33]

The diagram on page iv shows the evolutionary origin of some species of giant groundsels. Steps 1 to 5 indicate the order in which different populations of giant groundsels appeared on different mountains and speciated. Start with step 1 on the diagram and work your way through to step 5. The following table shows the names of the species and the abbreviations used in the diagram.

Table showing giant groundsel species' names and abbreviations used in the diagram on page iv.

Giant groundsel species' name	**Abbreviation**
Dendrosenecio kilimanjari	*Dk*
Dendrosenecio battiscombei	*Db*
Dendrosenecio brassiciformis	*Dbr*
Dendrosenecio meruensis	*Dm*
Dendrosenecio johnstoni	*Dj*

Biogeographical origin of giant groundsels (genus *Dendrosenecio*) in Kenyan mountains.



[Adapted: Knox, E. B. 2004. Adaptive Radiation of African Montane Plants. In Dieckmann, U., Doebeli, M., Tautz, D & Metz, J. A. J. *Adaptive Speciation*. Cambridge University Press. p. 476] [Adapted: Knox, E. B. & Palmer, J. D. 1995. Chloroplast DNA variation and the recent radiation of the giant senecios (Asteraceae) on the tall mountains of eastern Africa. *Proc. Natl. Acad. Sci. USA* 92: 10349-10353 <http://media.springernature.com>; <https://ai2-s2-public.s3.amazonaws.com>; <http://iucnredlist-photos>; <http://ryanphotographic.com>]

QUESTION 2

Read the information below. Use this information, as well as your own knowledge to answer Question 2 in the question paper.

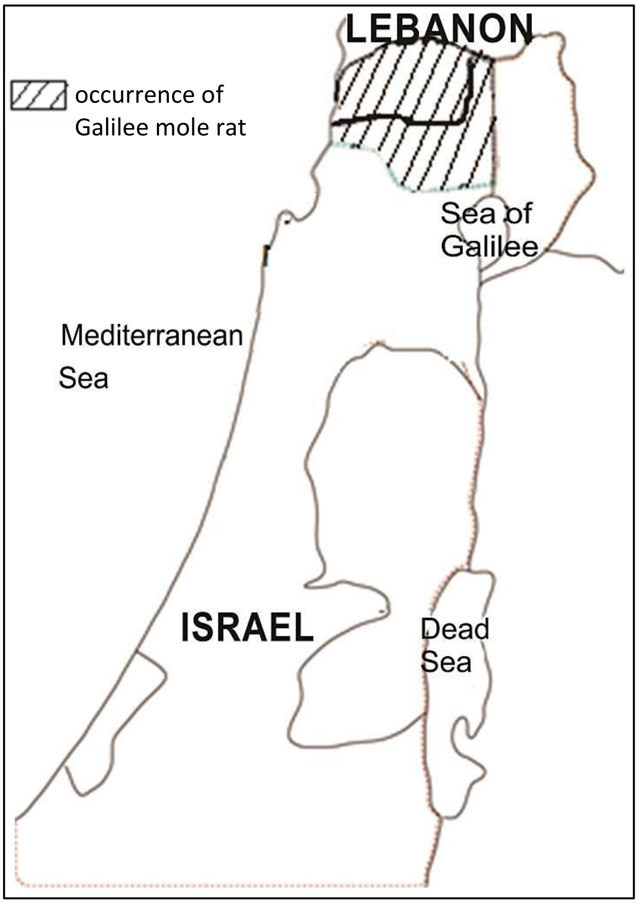
BLIND MOLE RATS SHOW EVOLUTION IN ACTION

Blind mole rats are a sightless group of burrowing rodents. Their eyes are present but are non-functional and are completely covered by a layer of skin.

There are many species of blind mole rat occurring in the Middle East. These species are all similar to one another but occur in different areas. One of these species, the Galilee mole rat, occurs in northern Israel and southern Lebanon.

Galilee mole rat
[Adapted: <https://www.researchgate.net/profile/>]

Map showing occurrence of Galilee mole rats



[Source: <http://ars.els-cdn.com>]

Sexual reproduction helps spread genes through a population. When a mountain or some other physical barrier blocks the flow of genes, speciation could occur – a population may evolve into two genetically distinct groups that are no longer able to interbreed successfully. But some scientists claim that there is another way for a new species to develop. They suggest that some individuals of a species can genetically diverge to become a new species even when there is no natural barrier between them. Natural variation means that some individuals in a population may behave differently from other individuals, and over time the differences can become great enough to prevent gene flow. Exactly how often this process of **sympatric speciation** occurs in nature remains a topic of hot debate.

Eviatar Nevo, an evolutionary biologist at the University of Haifa in Israel, thinks that sympatric speciation could be much more common than is generally believed – and he says that he has found a method to help prove it. His team has been studying the Galilee mole rat in a small area of northern Israel. In this area, there is a sharp geological boundary separating hard chalk rock and soft chalk rock. These rock types result in totally different types of soil. Different plant species also grow in each soil type. Galilee mole rats are found in both the hard and soft chalk soils. Nevo's team examined mitochondrial DNA in Galilee mole rats from hard chalk and from soft chalk habitats. Although the mole rats in the two soil types are not geographically separated and look very similar, up to 40% of the mtDNA differed between the animals in the two regions, suggesting limited gene flow.

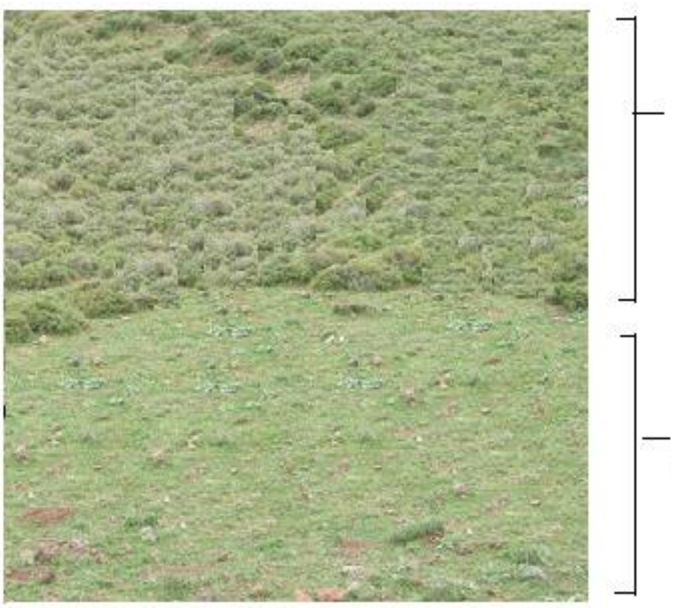


Photo showing the different types of vegetation growing in the hard and soft chalk soils

[Adapted: <https://www.researchgate.net/profile/Shay_Tzur/publication>]

mtDNA analysis indicates that the two groups diverged about 0,2–0,4 million years ago. In addition, the team found differences in certain genes between the hard and soft chalk soil populations. They have preliminary evidence that female and male Galilee mole rats taken from one soil type prefer to mate with each other, even in the presence of mole rats from the other soil type. Despite being the same species, the two populations appear to have mostly stopped mating with one another at some point in the past.

[Adapted: Hadid, Y., et al. 2013. Possible incipient sympatric ecological speciation in blind mole rats (*Spalax*). *Proc. Natl Acad. Sci. USA.* 110 (7) 2587–2592
Adapted: Shapiro J. A. 2011. Natural selection and natural genetic engineering. In: Evolution: A View From the 21st Century
Adapted: Li, K., et al. 2015. Sympatric speciation revealed by genome-wide divergence in the blind mole rat *Spalax. Proc Natl Acad Sci U S A.* 22: 112(38): 11905–11910
Adapted: Fitzpatrick, B. M.,et al. 2008. What, if anything, is sympatric speciation? *Epub* 21(6): 1452–9]

Hard chalk soil holds more water than soft chalk soil in winter. This means that Galilee mole rats in hard chalk soils receive less oxygen, potentially leading to quicker cell death. Researchers noted that a mutation in codon 172 of a gene called ***p53*** is more common in the hard chalk population. The normal ***p53*** allele allows cells to die when conditions are unfavourable (e.g. a low oxygen concentration). The mutant allele prevents this from happening, allowing the cells to survive longer in low oxygen environments.

The two populations live side-by-side today, but there is still debate about whether they will become genetically different enough to be considered separate species.

Eviatar Nevo says that, given enough time, the Galilee mole rats living in hard chalk soils may become so genetically distinct that they are no longer able to breed with Galilee mole rats living in soft chalk soil at all—in other words, he thinks his results show sympatric speciation in action.

However, Jerry Coyne, an evolutionary biologist at the University of Chicago in Illinois, is unconvinced. Only time will tell if the two mole rat populations truly become incapable of interbreeding – until they do, it's too soon to add this to the small number of confirmed sympatric speciation events. "We plan to conduct additional habitat and mate-choice experiments, which are the decisive indication of the origin of a new species," Nevo replied.

[Adapted: <evolution.haifa.ac.il>]
Adapted: Zhao, Y., et al. 2016. Adaptive methylation regulation of *p 53* pathway in sympatric speciation of blind mole rats, *Spalax. Proc. Natl. Ac. Sci. USA* 113(8): 2146-2151]
Adapted: <https://www.asianscientist.com>]

SECTION B

QUESTION 3

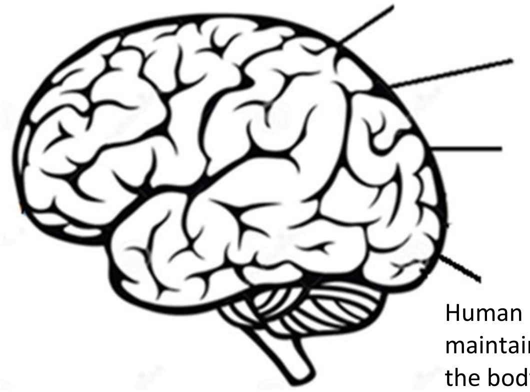
Read the information below. Use this information as well as your own knowledge to answer Question 3 in the question paper.

SOURCE A

SELECTION PRESSURE – This is when a factor in the environment causes an organism with a particular characteristic to survive, in preference to another individual of the same species with a different characteristic.

[Adapted: <i-base.info/selective-pressure>]

Brain size and the two selection pressure hypotheses

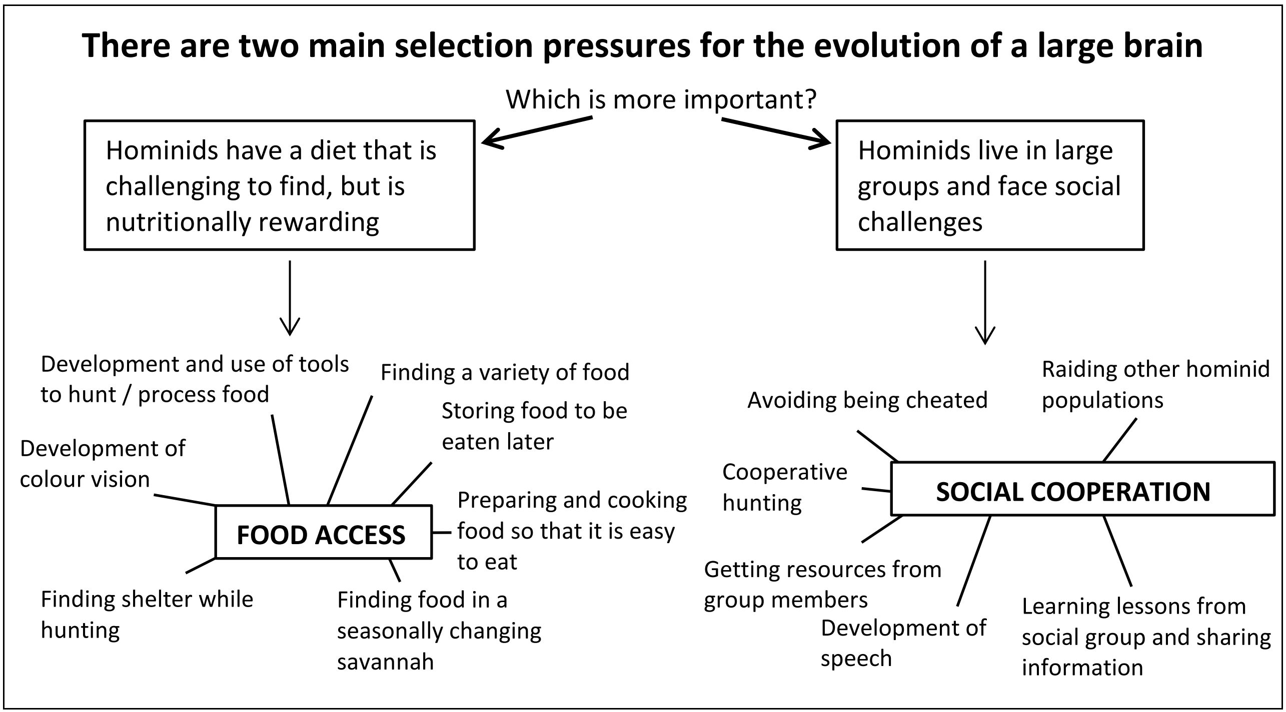


Possible selection pressures for the evolution of hominid brain size

SOCIAL COOPERATION

ABILITY TO ACCESS FOOD

[Adapted: <https://static.scientificamerican.com>]



[Adapted: González-Forero, M. & Gardner, A. 2018. Inference of Ecological and Social Drivers of Human Brain-size Evolution. *Nature* 557: 554–557]

SOURCE B BRAIN SIZE CORRELATIONS

Australopithecus afarensis
BRAIN SIZE: 400–500 cm^3; small forehead
TEETH AND DIET: adapted to eating leaves
TOOL USE: simple tools

Australopithecus africanus
BRAIN SIZE: 600 cm^3; small forehead
TEETH AND DIET: adapted to eating leaves and fruit
TOOL USE: sticks, stones, no evidence of tool modification

Homo habilis
BRAIN SIZE: 650 cm^3; large increase in Broca's area – where language is controlled
TEETH AND DIET: adapted to eat a wide range of fruit
TOOL USE: simple choppers and scrapers

Homo neanderthalensis
BRAIN SIZE: 1 500 cm^3; large increase in Broca's area
TEETH AND DIET: adapted to eat a wide variety of fruit, nuts, grains and meat
TOOL USE: complex tool use and modification

[Adapted: How has the human brain evolved over the years? 2013. *Scientific American* 24 (3): 76; <http://humanorigins.si.edu>; <https://pages.vassar.edu>; <https://australianmuseum.net.au>; <https://d330gly30227z7.cloudfront.net>; <http://www.nhm.ac.uk>; <nytimes.com>; <https://sep.yimg.com>]

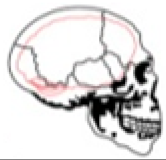
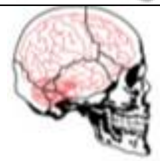
SOURCE C SOCIAL FACTORS – CORRELATIONS WITH BRAIN SIZE

It takes a huge amount of mental ability for humans to exist in their large social groups. This constant interaction creates high stress levels. Therefore Oxford anthropologist Robin Dunbar argues our huge brain is primarily developed to keep track of rapidly changing social relationships. If an individual falls out of the group, it loses access to food and mates.

Interaction with other group members involves the ability to manipulate other individuals effectively in order to gain the best resources and mates. It is also an advantage for group members to *avoid* manipulation. Those individuals who can do this effectively will leave more descendants. An individual with a larger brain will be able to manipulate (and avoid manipulation).

[Adapted: <https://theconversation.com>]

Table showing community size and brain size of different hominid species

Species	**Brain size (cm^3)**	**Average community size (number of individuals)**	
Paranthropus boisei	550	45	
Australopithecus africanus	600	48	
Homo habilis	650	50	
H. erectus	800	90	
H. neanderthalensis	1 500	125	
H. sapiens	1 300	150	

[Adapted: <36humanevolution.com>]

[Adapted: Reader, S. M. & Laland, K. N. 2002. Social intelligence, innovation, and enhanced brain size in primates. *Proc. Natl. Acad. Sci. USA*: 99(7): 4141–4142]

When two individuals A and B are involved in an aggressive encounter and a third, C, joins the fight in support of one of them, an alliance can be formed. Primates and hominids make alliances strategically, competing for support from more powerful individuals. This means that hominids must have a brain advanced enough to evaluate the group members in terms of what they can get out of them.

Evaluating the strengths and weaknesses of other individuals is also an advantage when one group raids another group for food and living space.

[Reader S. M. & Laland, K. N. 2002. Social intelligence, innovation, and enhanced brain size in primates. *Proc. Natl. Acad. Sci. USA*: 99(7): 4141–4142]

Manipulation is common in humans…

"But enough about me, now let's talk about your money".

[Adapted: <http://straightfromthea.com>]

SOURCE D LANGUAGE & CHILD REARING

Evidence indicates that the earliest hominids evolved in Africa and two million years later, some migrated to Asia. Migration in large numbers required hominids to have a means of communication for teamwork and collaboration. There was therefore a strong selection pressure for the development of primitive language.

As social structures increased in sophistication over time, co-operative hunting became possible in order to bring down larger prey. This also required a high level of communication.

[Adapted: <https://previews.123rf.com>]

[Adapted: Bailey, D. H., & Geary, D. C. 2009. Hominid brain evolution. *Human Nature* 20(1): 67–79]

Emotions and their probable evolutionary advantage

The development of emotions, which requires an increase in brain complexity, makes group communication and the manipulation of group members more effective.

Emotion	**Evolutionary advantage**
Disgust	Warning of dangerous food
Happiness	Signifies absence of threat to group
Sadness	Gain sympathy from group members
Anger	Warning/to signal dominance
Pride	Increased social status
Shame	Decreased social status/wish for forgiveness

[Adapted: Shariff, A. F. & J. L. Tracy. 2011. What are emotional expressions for? *Current Directions in Psychological Science*: 20(6): 395]

The length of time that children depend on parents is correlated with brain size: the longer children remain with parents, the more they can learn. However, in order to learn, both the children and parents require large brains – the children to learn and the parents to teach.

[Adapted: <http://www.livescience.com>]

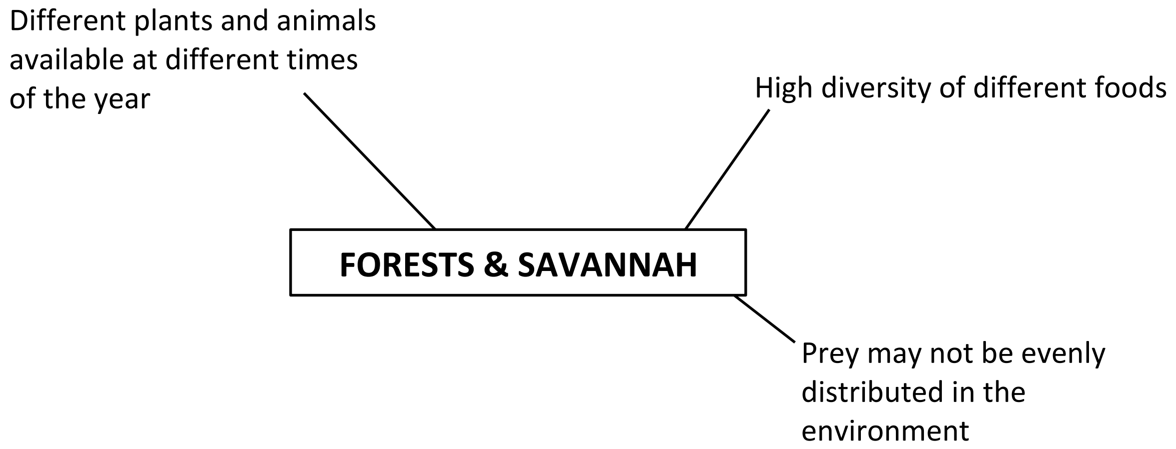
SOURCE E FRUIT

Brain size is bigger in species that are fruit-eating or omnivorous than in species that eat leaves. This is because species that feed on fruit face special problems in: (i) learning to recognise fruit that is ripe or safe to eat and (ii) remembering where they found fruit because they depend on finding fruit that is widely spaced (patchy) in both space and time.

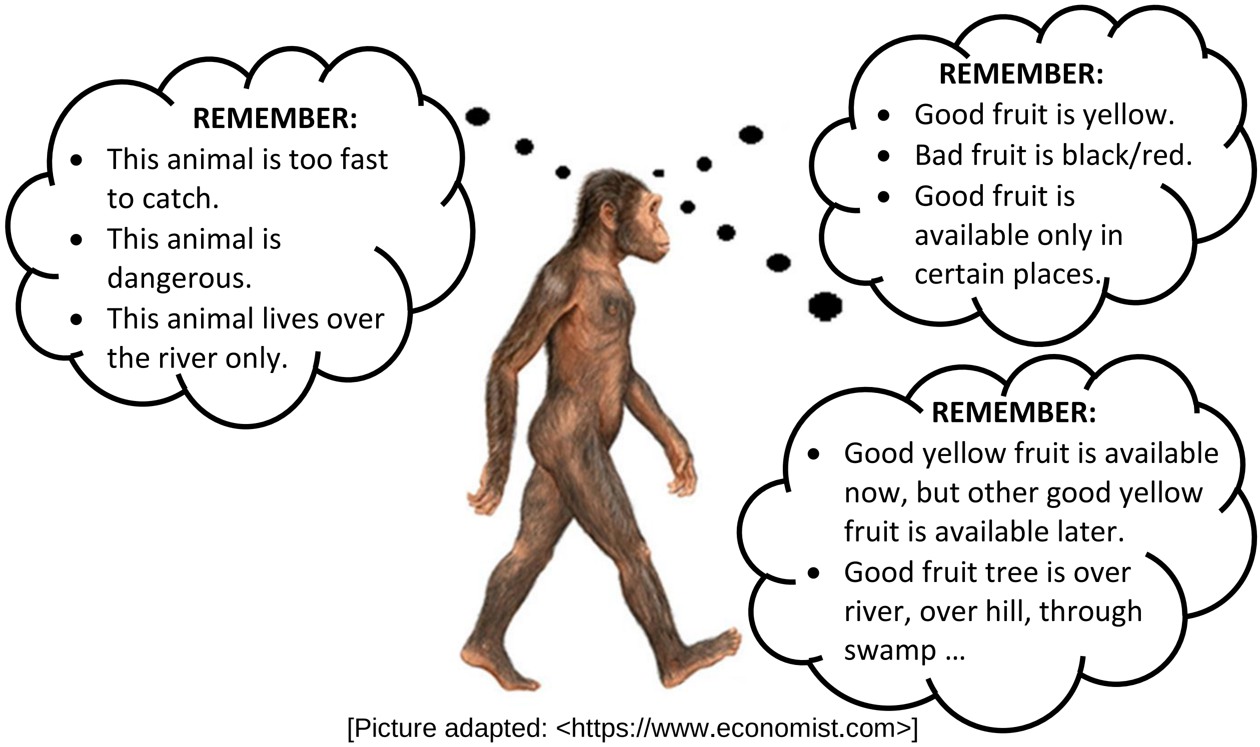
[Adapted: Reader, S. M. & Laland, K. N. 2002. Social intelligence, innovation, and enhanced brain size in primates. *Proc. Natl. Acad. Sci. USA*: 99(7): 4141–4142]

Because some fruits may be hard to reach or are protected by defences like spines, primates also need problem-solving skills or even tools to access fruit. Evolution could have pushed fruit-eating primates to develop bigger brains to deal with reaching food or handling dangerous food items.

[Adapted: deCasien, A. R., et al. 2017. Primate brain size is predicted by diet but not sociality. *Nature Ecology & Evolution* 1: 112]



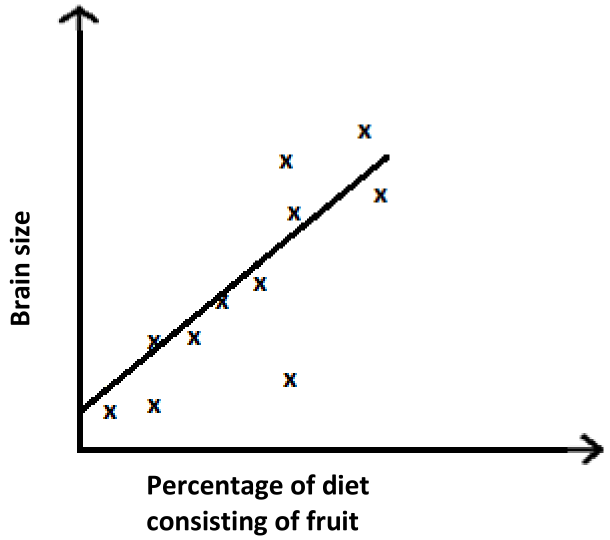
Selection pressures for the evolution of a large brain



[Picture adapted: <https://www.economist.com>]

[Adapted: Khanna, D. R. 2004. *Human Evolution*. Discovery Publishing House, New Delhi]

The graph shows, for different species, the correlation between the percentage of their diet consisting of fruit and their brain size

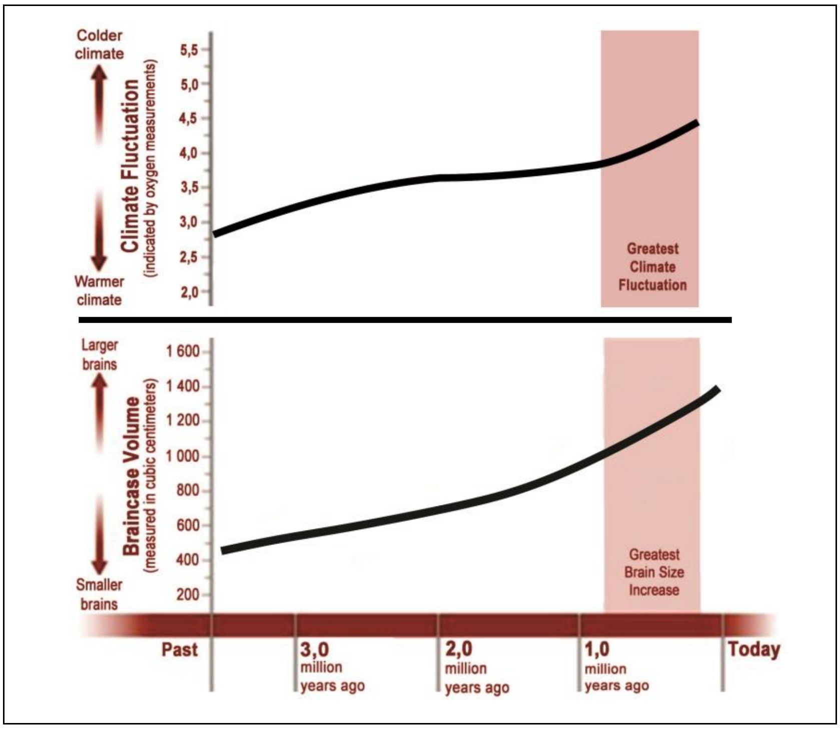


[Adapted: deCasien, A. R., et al. 2017. Primate brain size is predicted by diet but not sociality. *Nature Ecology & Evolution* 1: 112]

SOURCE F CLIMATE CHANGE

Human brain size evolved most rapidly during a time of dramatic climate change. Larger, more complex brains enabled early humans of this time period to interact with each other and with their surroundings in new and different ways. As the environment became more unpredictable, bigger brains helped our ancestors survive.

WHY THE SUDDEN INCREASE IN BRAIN SIZE?



[Smithsonian Museum of Natural History]

SOURCE G EXPERIMENTAL EVIDENCE

Tool use is often cited as a selection pressure for the evolution of large brains. For example, monkeys and apes use tools and their brains are significantly larger than those of similar-sized mammals.

1 100 scientific investigations concerning primate behaviour were analysed for examples of tool use, and innovation in tool use. This was compared to brain size of the species concerned.

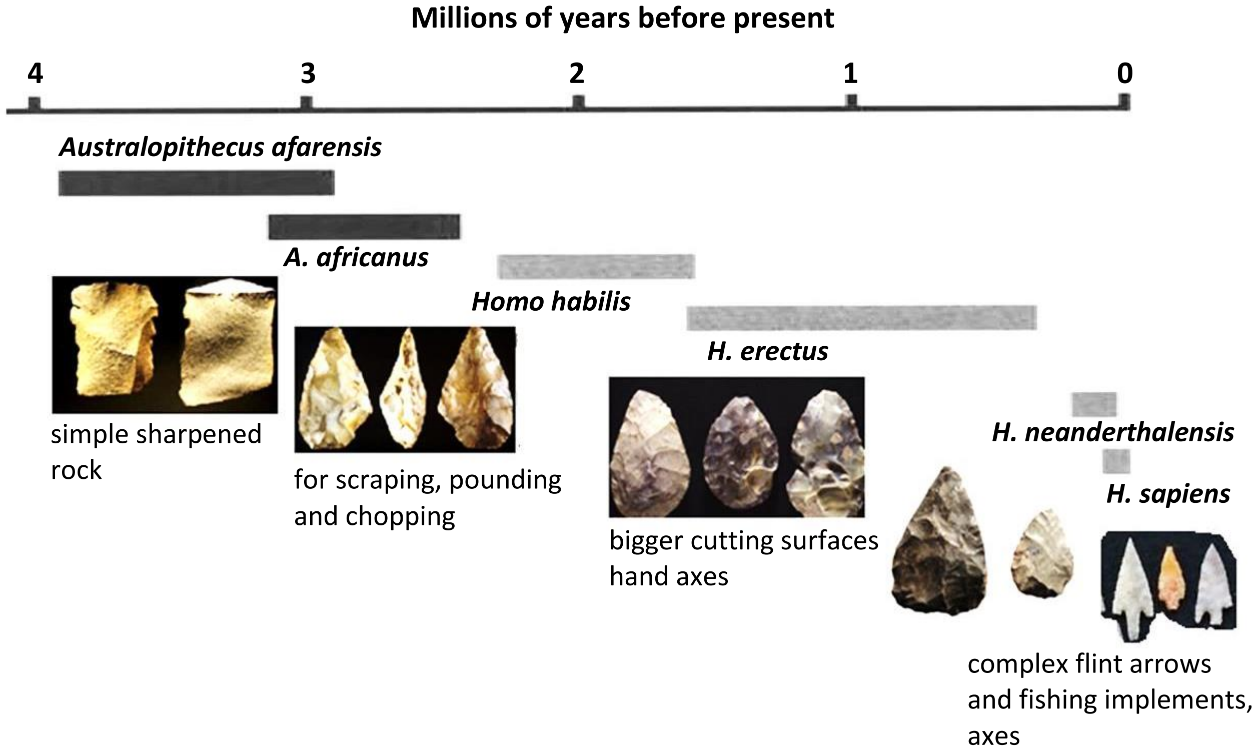
"Innovation in tool use" refers to tools that are manufactured, such as sticks being used in novel ways (e.g. to collect termites). The more innovation in a species, the bigger their brains.

Chimpanzee collecting termites with a stick
[Adapted: <https://images.newscientist.com>]

[Adapted: Seyfarth, R. M. & Cheney, D. L. 2002. What are Big Brains for? *Proc. Natl. Acad. Sci. USA* 99(7): 4141-4142]

SOURCE H TOOL USE & COOKING

Tool use in different hominid species



[Adapted: <https://i.pinimg.com>; <http://4.bp.blogspot.com>; <https://www.researchgate.net>; <http://www.bradshawfoundation.com>; <https://i.ebayimg.com>]

Fishing requires a large brain to track tides and to develop tools required to fish and tools needed to force open shellfish such as oysters and mussels.

[Adapted: Acedo Carmona, C & Gomila A. 2016. A critical review of Dunbar's social brain hypothesis. *Revista Internacional de Sociologica* 74(3): 37]

Large brain size could also be linked to the evolution of cooking. Those individuals with a brain that could work out how to cook food may have had an advantage as cooked foods tend to be softer than raw ones, so humans can eat them with smaller teeth and weaker jaws. Cooking also increases the energy they can get from the food they eat. For example, starchy potatoes and other tubers, eaten by people across the world, are not digestible when raw.

Anthropologist Richard Wrangham has proposed that cooking arose before 1,8 million years ago. If the custom emerged this early, it could explain a defining feature of our species: the increase in brain size that occurred around this time.

[Adapted: Food for Thought: Was Cooking a Pivotal Step in Human Evolution? <https://www.scientificamerican.com>]