A

Aging Definition

Giacinto Libertini
ASL NA2 Nord, Italian National Health Service, Frattamaggiore, Italy
Department of Translational Medical Sciences, Federico II University, Naples, Italy

Synonyms

Senescence

Definition

Aging may be defined in two ways that could be considered equivalent. The first describes the phenomenon as an age-related decline of biological functions, e.g., "progressive loss of function accompanied by decreasing fertility and increasing mortality with advancing age" (Kirkwood and Austad 2000, p. 233); "a persistent decline in the age-specific fitness components of an organism due to internal physiological deterioration" (Rose 1991, p. 38); and "any time-dependent change which occurs *after* maturity of size, form, function is reached and which is distinct from daily, seasonal and other biological rhythms" (Rockstein et al. 1977, p. 4). The second way describes the phenomenon as an age-related increase in mortality, i.e., "increasing mortality with increasing chronological age in populations in the wild" (Libertini 1988, p. 145) or "actuarial senescence" (Holmes and Austad 1995, p. B61), or "age-dependent increase in the risk of death" (Lenart et al. 2018, p. 1), which are equivalent to the first if the definitions are always restricted to observations in the wild. In fact, in natural conditions, the decline of biological functions means a decline of Darwinian fitness to survive, i.e., a mortality increase.

However, it should be noted that mortality rate is a measurable parameter, while the decline of biological functions is something that would require a precise definition to allow exact and unbiased measurements. This appears difficult or impossible unless one means the decline of biological functions as synonym of Darwinian fitness decline, a specification that transforms the first definition into the second one. It is therefore preferable to define aging as "age-related increasing mortality (= decreasing Darwinian fitness)" and to emphasize that to avoid misunderstandings due to captive/protected conditions or unhealthy lifestyles, it is important to add the restriction "in the wild."

Presence of Aging in the Wild

The first type of definition should also be avoided because it may lead to confusion between the aging process and the condition of evident impairment of biological functions in older subjects. In fact, in authoritative works, it is possible to read

D. Gu, M. E. Dupre (eds.), *Encyclopedia of Gerontology and Population Aging*,
https://doi.org/10.1007/978-3-319-69892-2_29-1

that: "... there is scant evidence that senescence contributes significantly to mortality in the wild. ... As a rule wild animals simply do not live long enough to grow old" (Kirkwood and Austad 2000, p. 233)); "... it is doubtful that many individuals would remain for study at the age at which laboratory populations exhibit aging" (Rose 1991, p. 21).

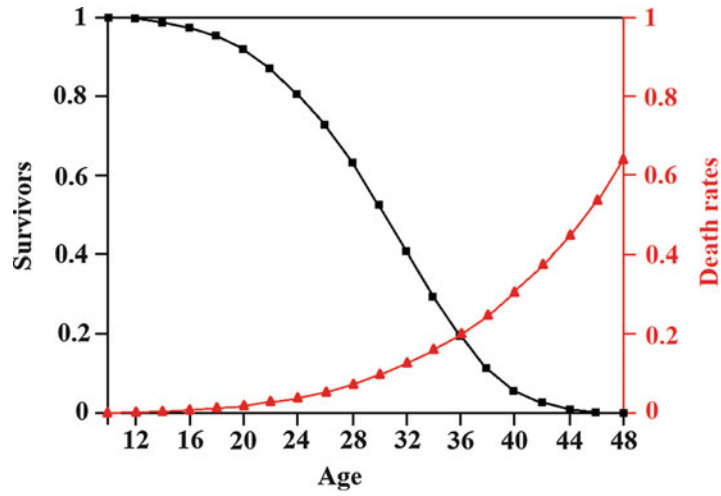
It is true that very old individuals (e.g., 90-year-old or older persons or their equivalent in animal species that age) are rare or absent under natural conditions and therefore contribute little or nothing to overall mortality, but this does not rule out that individuals of younger ages – when the mortality is already increasing – are widely present in natural conditions and that their death contributes strongly to the overall mortality.

The presence of an age-related increase in mortality under natural conditions has long been known (Libertini 1988; Finch 1990; Ricklefs 1998). A review has stated: "The recent emergence of long-term field studies presents irrefutable evidence that senescence is commonly detected in nature. We found such evidence in 175 different animal species from 340 separate studies" (Nussey et al. 2013, p. 214). An example of life table and death rates for a species observed in the wild is illustrated in Fig. 1.

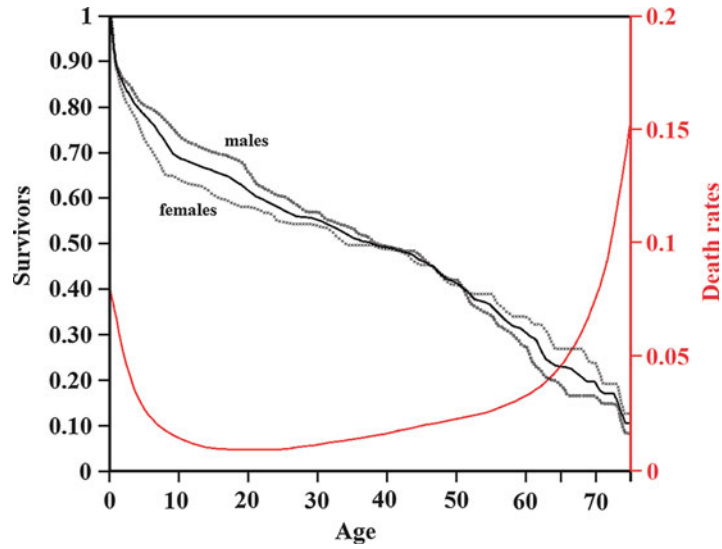
As for our species, in modern conditions: "No one would consider a man in his thirties senile, yet, according to athletic records and life tables, senescence is rampant during this decade" (Williams 1957, p. 399) (for the athletic records, see (Wikipedia, entry List of world records in masters athletics)). This claim is confirmed in the observation of life table and mortality curve of a human population studied under natural conditions (Hill and Hurtado 1996). This population (Ache people of Paraguay) showed a mortality increase that started in the third decade of life, but despite the really primitive conditions and the high mortality due to violent causes or other causes that would be lethal at any age, the study highlighted that the ages of 60, 65, 70, and 75 years survived about 31%, 24%, 21% and 11%, respectively, of the individuals (Hill and Hurtado 1996) (Fig. 2).

Effects of Aging on Life Span

Another belief, unfounded but which also finds its place in the best scientific literature, is that aging, under natural conditions, affects little or nothing the mean duration of life (Kirkwood and Austad 2000). However, already in 1988, on the basis of data available for some time, it was shown that, without the age-related increase in mortality that defines aging, the average life expectancy would have doubled. In addition, by excluding individuals who died in the first phases of life, when mortality is higher but there is still no increase in



Aging Definition, Fig. 1 Life table of hippopotamus (*Hippopotamus amphibius*) in the wild, excluding the first years of life when the mortality is higher. (Data from Ricklefs 1998)



Aging Definition, Fig. 2 Life table (females, males, mean) and death rates of Ache people in the forest period. (Data from Hill and Hurtado 1996)

Aging Definition, Table 1 For various mammal species, sex combined: Ratio 1, ratio between the life span under natural conditions and the life span in the hypothetical condition that the mortality rate remains stable on its lowest value (L and L_h are the areas defined by the real-life table and by the hypothetical life table, respectively); Ratio 2, ratio between the life span under natural conditions but considering only the survivors after the first periods of life, i.e., when mortality reaches its lowest value, and the life span in the hypothetical condition that the mortality rate remains stable on its lowest value (L[e] and $L[e]_h$ are the areas defined by the real-life table and by the hypothetical life table, respectively, but excluding part of the population as before said)

Species	Source of data	Ratio 1 L/L_h	Ratio 2 $L[e]/L[e]_h$
Buffalo	Spinage (1972)	2.21	3.46
Dall mountain sheep	Deevey (1947)	3.21	5.09
Elephant	Laws (1966)	1.67	2.42
Hippopotamus	Laws (1968)	2.81	4.45
H. sapiens (Ache people)	Hill and Hurtado (1996)	2.26	3.04
Impala	Spinage (1972)	2.64	3.85
Waterbuck	Spinage (1970)	2.57	4.02
Warthog	Spinage (1972)	1.55	2.85
Zebra	Spinage (1972)	2.03	3.20

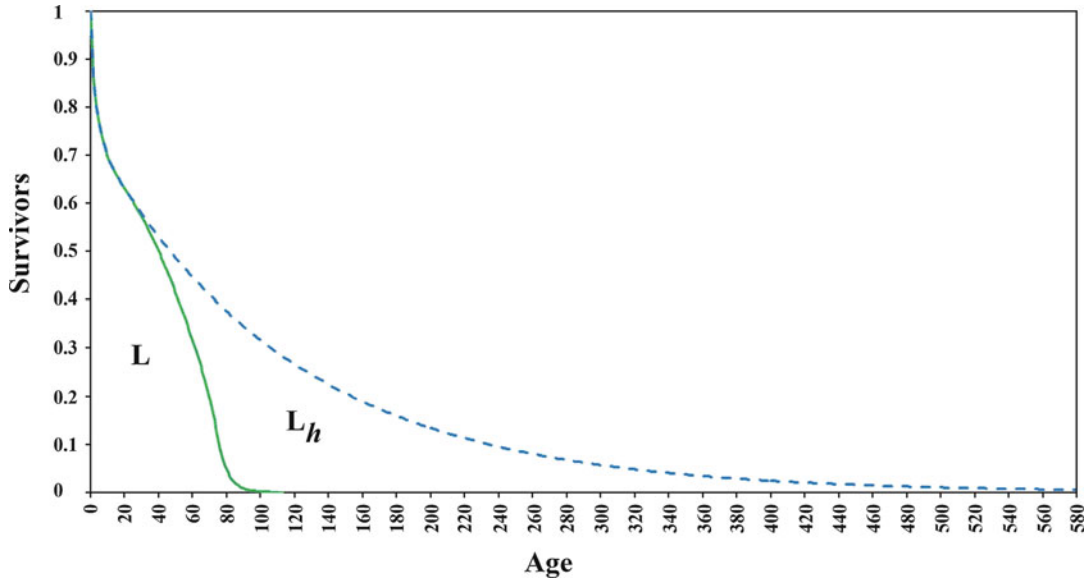
Table from Libertini (2013), modified

age-related mortality, the duration of life would have tripled or even multiplied by a factor of 4 or 5 (Libertini 1988). These calculations were re-proposed in 2013 with the addition of data on human species studied under natural conditions (Libertini 2013) (Table 1 and Figs. 3 and 4).

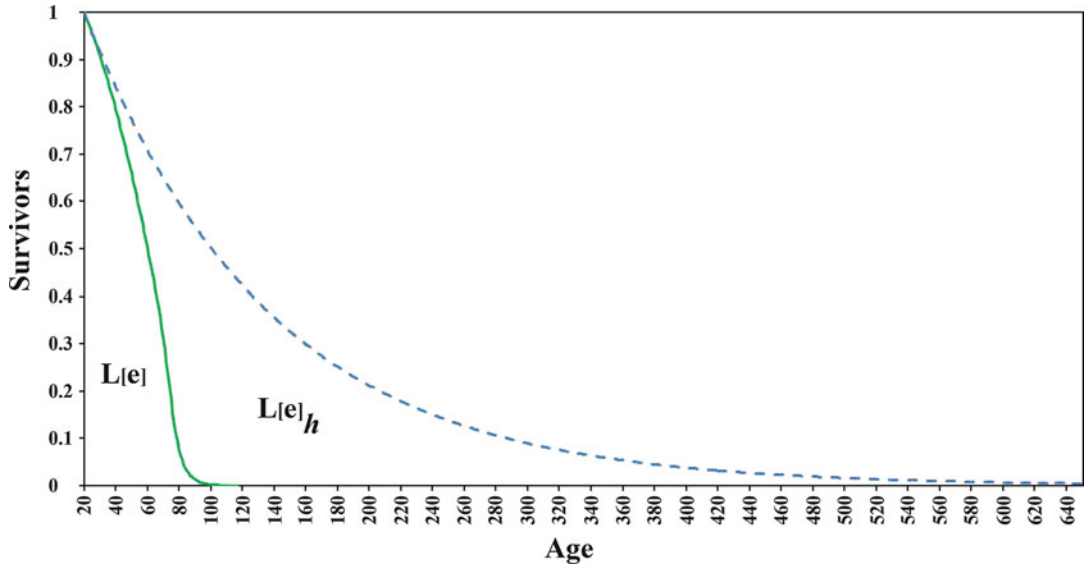
In 1998, with data from the observation in the wild of many species and with similar calculations, Ricklefs showed that the proportion of deaths due to senescence (P_s in Ricklefs' work; it is the ratio $[L_h\text{-}L]/L_h$) if we follow the definitions of Table 1 and Fig. 3) was relevant in all aging species (Ricklefs 1998).

Evaluation of Age-Related Decline in Biological Functions

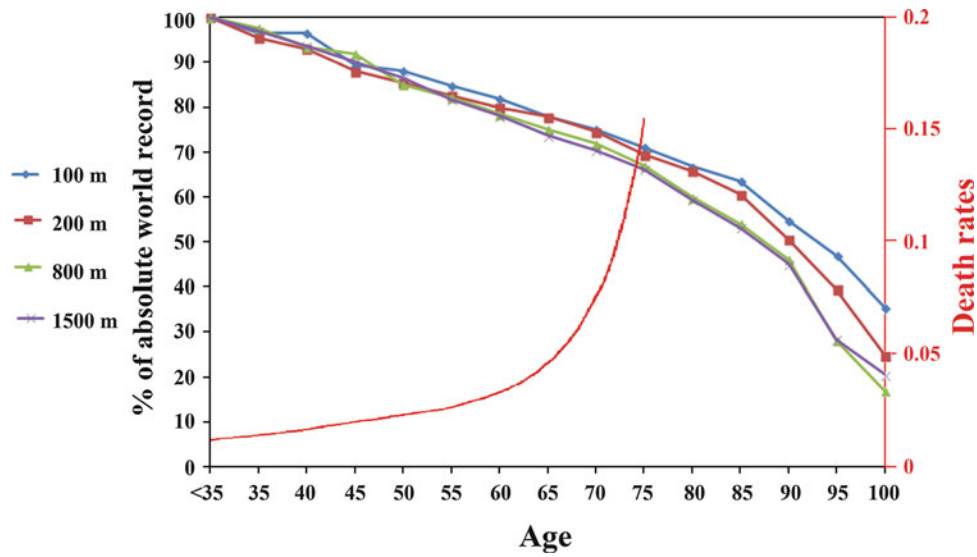
For our species it is possible to estimate with ease the age-related decline of biological functions by



Aging Definition, Fig. 3 Continuous line, life table of Ache people under natural conditions (forest period), data from (Hill and Hurtado 1996); dashed line, hypothetical life table without any age-related increasing mortality. L and L_h are the areas defined by the real-life table and by the hypothetical life table, respectively. Under wild conditions (forest period), the life span of Ache was estimated to be 38.8 years. In the hypothetical life table, where the lowest mortality (0.9%/year at the ages of 20–30 years) does not increase with age, the life span would have been 87.85 years with a ratio (Ratio 1) between the two values equal to 2.26. It is worth noting that in the hypothetical life table at the age of 580 years (!), about 0.5% of the population would survive (Libertini 2013)



Aging Definition, Fig. 4 The same with Fig. 3, but only individuals not dead before the age of 20 years are considered. L[e] and $L[e]_h$ are the areas defined by the real-life table and by the hypothetical life table, respectively, but excluding the individuals dead before the age of 20 years. With this condition, the life span of Ache under natural conditions was estimated to be 20 + 38.1 = 58.11 years. In the hypothetical life table, the life span would have been 20 + 116.04 = 136.04 years. The ratio (Ratio 2) between the two values would be equal to 3.044, and about 0.5% of the population would survive at the age of 634 years (Libertini 2013)



Aging Definition, Fig. 5 Age-related decline of world records for running races. The fitness decline is related to this decline in maximum performance, but the relationship is not linear. In fact, by comparing the decline of maximum performance with mortality under natural conditions, a performance decline of about 35–40% practically leads to a zeroing of survival capacity, i.e., of fitness. (Data sources for current world records in the various age groups from Wikipedia (2018); data source for human mortality under natural condition, for Ache people, from Hill and Hurtado (1996))

the simple examination of world records divided by age groups for various sports. These data are shown in Fig. 5 for running races and in Fig. 6 for other types of competition in which muscle strength is more important. The absolute world records are obtained by individuals under 35, that is, before the period in which mortality begins to grow. Records for each age group are expressed as a percentage of absolute world records.

The records in the various types of competitions are a reliable index of the maximum that individuals presumably in optimal conditions can express. The curve of the percentile values of the records is compared with the curve of death rates under natural conditions. These two images allow easy and immediate considerations.

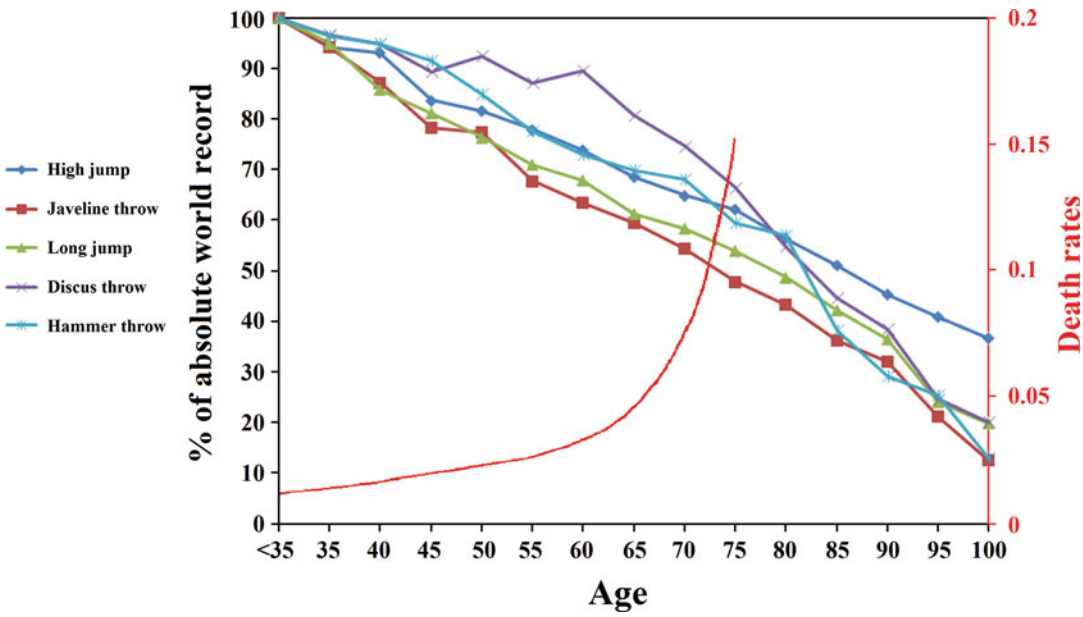
First of all, the value of performance, which is an expression of physical fitness, is not synonymous with Darwinian fitness, that is, the capacity for survival and reproduction in natural conditions. In fact, when, around the age of 75, there is a loss of about 30% of the speed in running races, and of about 40% in races where muscle strength has greater value, mortality in the wild rises dramatically, and older individuals are rare or nonexistent, i.e., Darwinian fitness is practically zeroed.

In modern protected conditions, despite the decline of biological functions which continues and even worsens (in the centenarian there is a loss of about 80–90%), a growing number of individuals survive. This does not mean a slowing down of the rhythms of aging but only the effect of protected and nonautonomous living conditions.

Non-universality of Aging

Aging, precisely defined as progressive age-related mortality increase under natural conditions, could seem a universal phenomenon among species, just as the deterioration with time of any inanimate object is universal. But this belief is widely contradicted by what is observed in the variegated living world (Finch 1990; Jones et al. 2014):

1. For many species, after a period with constant mortality (i.e., without evidence of aging), in a



Aging Definition, Fig. 6 Age-related decline of world records for other types of competitions compared with human mortality under natural condition. Here too a performance decline of around 35–40% leads to a fitness decline that is incompatible with survival under natural conditions. (Data sources are the same of the previous figure)

short time there is a total decay and the death of the individual.

For example, in many plants, in particular monocarpic angiosperms, the reproductive phase of flowering and fruiting is soon followed by a rapid decay and the death of the plant (Leopold 1961; Finch 1990). Plant senescence is considered by botanist an active and orderly process, i.e., not determined by random factors or depending on unsurpassable physiological constraints (Leopold 1961; Noodén and Leopold 1988). For plants "Senescence is regarded as an evolutionarily acquired process" (Woo et al. 2018).

Moreover, the decay and the death when the reproductive phase is reached does not mean that a plant must necessarily have a short life span. Mediterranean *Agave* may grow vegetatively for up to 100 years before flowering (Molisch 1938), and *Puya raimondii*, a perennial monocarp, may mature and flower at the age of 150 years (Raven et al. 1986).

Many species of salmons, eels, cephalopod, and gastropod mollusks show after spawning a rapid deterioration of the organism and the consequent death (Finch 1990). This sudden decay is regulated by hormones, i.e., it is genetically programmed: in *Octopus hummelincki* the removal of the optic gland after spawning increased by two- to threefold the life span and restored the capacity of feeding and growing (Wodinsky 1977).

2. In some species, the birth causes the obligatory death of the mother (Finch 1990). The eggs of Rhabdocoela flatworms are fertilized internally to the mother, and in the birth the young must bore through the body wall of the mother killing her (Hyman 1951). The embryos of the beetle *Micromalthus debilis* remain stuck to the body of the mother, and their development, followed by pupation and hatching, is obtained through the cannibalization of the mother (Scott 1941).
3. For many other species, in particular among insects, larval phases, in which the individual nourishes and grows without showing any age-related mortality increase, alternate with an adult phase, derived from the transformation of the previous one and destined only for

reproduction, in which insect has a limited life. At this stage the insect has no cell renewal capacity and is therefore subject to wear phenomena resulting in death (Comfort 1979): "... the insects [are] at risk for debilitating damage to irreplaceable cells and organs, particularly to their fragile wings and exoskeleton, which Comfort (1979) has called mechanical senescence" (Finch 1990, p. 62).

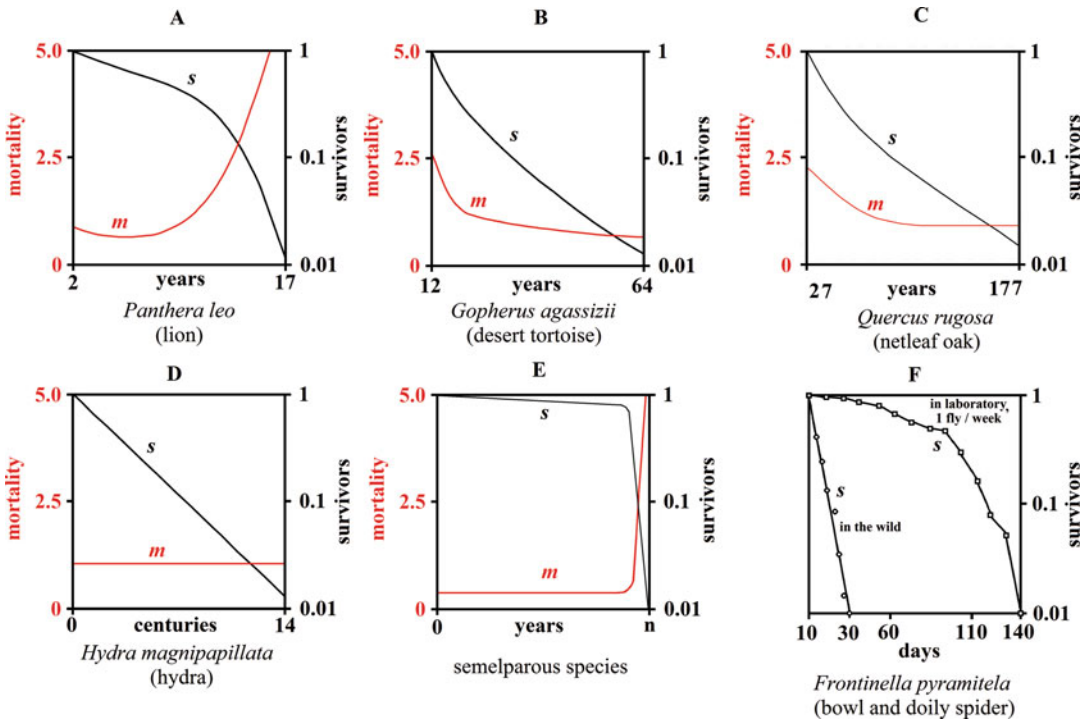
The fly *Drosophila melanogaster* is a famous example of such cases: when it is bred in protected conditions, it survives at a later age but undergoes, among other things, phenomena of mechanical degradation of the wings and other parts that determine its death.

For many species of insects, the genetic programming of the limited life span of the adult phase is evident and indisputable. The most striking case is that of aphagy, i.e., the inability to feed: "Aphagy from defective mouthparts or digestive organs is very common during the adult phase of insects ... and is *the* limiting factor in the adult lifespan of many short-lived species" (Finch 1990, p. 62).

4. An opposite case it that of many species "at all grades of organization that do not show indications of whole-organism senescence, [and] that do not show age related increases of mortality risks" (Finch 1990, p. 207). These non-aging species have been prudentially defined as species with "negligible senescence" (Finch 1990, p. 206). The list of species with negligible senescence is long, and only few examples are here mentioned: (i) in a study, 3% of individuals of *Sequoia sempervirens* were older than 1000 years (Harper 1977); (ii) for the ocean quahog (*Arctica islandica*), a living and healthy individual older than 500 years was found (Sosnowska et al. 2014); and (iii) rockfish, sturgeon, turtles, bivalves, and possibly lobsters were found (Finch and Austad 2001). In such species, individuals are not immortal as sooner or later they die from predation or other accidental causes.

   In some species that show no sign of age-related functional decline, as size increases with time and vulnerability to predation is reduced, the mortality rate even decreases with age. These species have been defined as species with "negative senescence" (Vaupel et al. 2004, p. 339), but the term is misleading: they are a special case of animals without evident senescence in which a particular characteristic that changes with age (i.e., size) reduces the mortality rate.
5. Finch, in the section "Finite Lifespans with Negligible Senescence" (Finch 1990, p. 222), considers the cases of species with short life spans, but that, under natural conditions, in their short life do not show signs of senescence or more precisely of age-related increased mortality. An example of such species is the fly *Drosophila melanogaster*.
6. For bacterial species and for most of the single-celled eukaryotic organisms that reproduce by division into two identical individuals, but also in the case of viruses, the concept of aging cannot be proposed.
7. An exception is made of those single-celled species, such as *Saccharomyces cerevisiae*, in which the progenitor originates by division two different individuals, defined as daughter and mother cells. While daughter cells have unlimited ability to reproduce and do not exhibit any functional alterations, the cells of the mother line show a limited ability to reproduce (Jazwinski 1993), increasing alterations of cellular functions and a growing vulnerability to apoptosis, related to the number of previous divisions (Lesur and Campbell 2004). The phenomena shown by *S. cerevisiae* have interesting analogies and phylogenetic correlations with aging as before defined (Libertini 2015a).

In short, within the living world, aging, in its precise definition of age-related mortality increase in the wild, is present only in a minority of species. Most species show quite different types of life tables (Jones et al. 2014) (Fig. 7). It is a source of confusion that these different life tables are often described as forms of aging. For example, the decay and the death of the deciduous plants is described as sudden senescence (Finch 1990). Similarly, the phenomena (mechanical wear and death of individuals) observed in laboratory for adult forms of insects kept under protected



Aging Definition, Fig. 7 Some examples of life Tables. (**a**), an aging species; (**b** and **c**), species with a constant mortality (after the first period of life with a higher mortality); (**d**), species with an always constant mortality; (**e**), scheme of life table of a semelparous species; (**f**), a species with a constant mortality in the wild and with an age-related increasing mortality in protected conditions. (Source of **a**–**b**: from Fig. 1 in Jones et al. (2014), partial, modified and redrawn; **e**, drawn according to Finch (1990); **f**, data from Austad (1989))

conditions do not fall into the definition of aging but are commonly described as senescence (Finch 1990).

The different life-table cases in which life span is clearly programmed, that is to say, somehow genetically regulated and with some adaptive value, should be defined with a general term different from that often used of senescence. In fact, it is not necessary to coin a new term as there is already the term phenoptosis defined as "programmed death of the body" (Skulachev 1997, p. 1191).

This term has also been applied to aging phenomenon, which has been considered a form of slow phenoptosis (Skulachev 2002).

The inclusion of aging in the large phenoptotic world, that is to say, among genetically programmed and modulated phenomena, is not accepted by a large majority of researchers who consider aging as a phenomenon that is certainly nonadaptive and non-programmed (Olshansky et al. 2002; Kowald and Kirkwood 2016).

However, if it is true that the supporters of the thesis of programmed aging are a minority, it is also true that, for life tables in which life span is limited, the thesis that these phenomena are programmed is largely prevalent (Finch 1990). Therefore, the interpretation of aging as a non-programmed phenomenon would be a strange exception.

Furthermore, the existence of many species in which there is no increase in mortality correlated with age should be explained by those who consider aging as caused by universal degenerative phenomena that cannot be counteracted by natural selection (Libertini 2015b).

Conclusion

There are some beliefs in the scientific world that are widespread and intrinsic to certain definitions of the concept of aging: (A) in aging species, aging individuals are rare or nonexistent under natural conditions; (B) because under natural conditions aging individuals are practically nonexistent, they have little influence on life table and life span; (C) due to the irrelevance of its effects on life table and life span, aging is scarcely or not at all influenced by natural selection; and (D) aging is universal in the living world. Many species have individuals who do not seem to age because they suffer from high mortality and live very little.

They appear contradicted by empirical evidence: (A) in aging species, aging individuals are present and common in natural conditions (Ricklefs 1998; Nussey et al. 2013); (B) aging significantly changes life table and life span (Libertini 1988; Ricklefs 1998); (C) due to its considerable effects on life table and life span, aging is strongly influenced by natural selection (Libertini 1988); and (D) aging is present only in a small part of the living species. Most species have survival curves of completely different types (Finch 1990; Jones et al. 2014).

Only if we start from real data and abandon beliefs rooted in tradition but that should be considered untenable in objective terms (Libertini 2015b) it is possible to study without prejudices aging, as defined above and rationally framed in the broad range of phenoptotic phenomena.

Cross-References

- Aging Mechanisms
- Aging Pathology
- Aging Theories
- Animal Models of Aging
- Biogerontology
- Non-evolutionary and Evolutionary Aging Theories
- Timeline of Aging Research

References

Austad SN (1989) Life extension by dietary restriction in the bowl and doily spider, Frontinella pyramitela. Exp Gerontol 24:83–92. https://doi.org/10.1016/0531-5565(89)90037-5

Comfort A (1979) The biology of senescence. Livingstone, London

Deevey ES Jr (1947) Life tables for natural populations of animals. Q Rev Biol 22:283–314. https://doi.org/10.1086/395888

Finch CE (1990) Longevity, senescence, and the genome. University of Chicago Press, Chicago

Finch CE, Austad SN (2001) History and prospects: symposium on organisms with slow aging. Exp Gerontol 36:593–597. https://doi.org/10.1016/S0531-5565(00)00228-X

Harper JL (1977) Population biology of plants. Academic, New York

Hill K, Hurtado AM (1996) Ache life history. Aldine De Gruyter, New York

Holmes DJ, Austad SN (1995) Birds as animal models for the comparative biology of aging: a prospectus. J Gerontol A Biol Sci Med Sci 50A:B59–B66

Hyman LH (1951) The invertebrates. Acanthocephala, Aschelminthes, and Entoprocta. The pseudocoelomate bilateria, vol 3. McGrave-Hill, New York

Jazwinski SM (1993) The genetics of aging in the yeast Saccharomyces cerevisiae. Genetica 91:35–51. https://doi.org/10.1007/978-94-017-1671-0_6

Jones OR, Scheuerlein A, Salguero-Gómez R et al (2014) Diversity of ageing across the tree of life. Nature 505:169–173. https://doi.org/10.1038/nature12789

Kirkwood TB, Austad SN (2000) Why do we age? Nature 408:233–238. https://doi.org/10.1038/35041682

Kowald A, Kirkwood TB (2016) Can aging be programmed? A critical literature review. Aging Cell 15(6):986–998. https://doi.org/10.1111/acel.12510

Laws RM (1966) Age criteria for the African elephant, Loxodonta a. africana. E Afr Wildl J 4:1–37. https://doi.org/10.1111/j.1365-2028.1966.tb00878.x

Laws RM (1968) Dentition and ageing of the hippopotamus. E Afr Wildl J 6:19–52. https://doi.org/10.1111/j.1365-2028.1968.tb00899.x

Lenart P, Bienertova-Vasku J, Berec L (2018) Evolution favors aging in populations with assortative mating and strong pathogen pressure. Sci Rep 8:16072. https://doi.org/10.1038/s41598-018-34391-x

Leopold AC (1961) Senescence in plant development. Science 134:1727–1732. https://doi.org/10.1126/science.134.3492.1727

Lesur I, Campbell JL (2004) The transcriptome of prematurely aging yeast cells is similar to that of telomerase-deficient cells. MBC Online 15:1297–1312. https://doi.org/10.1091/mbc.e03-10-0742

Libertini G (1988) An adaptive theory of the increasing mortality with increasing chronological age in populations in the wild. J Theor Biol 132:145–162

Libertini G (2013) Evidence for aging theories from the study of a hunter-gatherer people (Ache of Paraguay). Biochem Mosc 78:1023–1032. https://doi.org/10.1134/S0006297913090083

Libertini G (2015a) Phylogeny of aging and related phenoptotic phenomena. Biochem Mosc 80(12): 1529–1546. https://doi.org/10.1134/S0006297915120019

Libertini G (2015b) Non-programmed versus programmed aging paradigm. Curr Aging Sci 8(1):56–68

Molisch H (1938) The longevity of plants (trans: Fulling H). Science Press, Lancaster

Noodén LD, Leopold AC (eds) (1988) Senescence and aging in plants. Academic, San Diego

Nussey DH, Froy H, Lemaitre JF et al (2013) Senescence in natural populations of animals: widespread evidence and its implications for bio-gerontology. Ageing Res Rev 12:214–225. https://doi.org/10.1016/j.arr.2012.07.004

Olshansky SJ, Hayflick L, Carnes BA (2002) Position statement on human aging. J Gerontol A Biol Sci Med Sci 57(8):B292–B927. https://doi.org/10.1093/gerona/57.8.B292

Raven PH, Evert RF, Eichhorn SE (1986) Biology of plants, 4th edn. Worth, New York

Ricklefs RE (1998) Evolutionary theories of aging: confirmation of a fundamental prediction, with implications for the genetic basis and evolution of life span. Am Nat 152:24–44. https://doi.org/10.1086/286147

Rockstein M, Chesky JA, Sussman M (1977) Comparative biology and evolution of aging. In: Finch CE, Hayflick L (eds) Handbook of the biology of aging. Van Nostrand Reinhold Company, New York, pp 3–34

Rose MR (1991) Evolutionary biology of aging. Oxford University Press, Oxford

Scott A (1941) Reversal of sex production in Micromalthus. Biol Bull 81:420–431. https://doi.org/10.2307/1537915

Skulachev VP (1997) Aging is a specific biological function rather than the result of a disorder in complex living systems: biochemical evidence in support of Weismann's hypothesis. Biochem Mosc 62:1191–1195

Skulachev VP (2002) Programmed death phenomena: from organelle to organism. Ann N Y Acad Sci 959:214–237. https://doi.org/10.1111/j.1749-6632.2002.tb02095.x

Sosnowska D, Richardson C, Sonntag WE et al (2014) A heart that beats for 500 years: age-related changes in cardiac proteasome activity, oxidative protein damage and expression of heat shock proteins, inflammatory factors, and mitochondrial complexes in Arctica islandica, the longest-living noncolonial animal. J Gerontol A Biol Sci Med Sci 69(12):1448–1461. https://doi.org/10.1093/gerona/glt201

Spinage CA (1970) Population dynamics of the Uganda Defassa Waterbuck (Kobus defassa Ugandae Neumann) in the Queen Elizabeth park, Uganda. J Anim Ecol 39:51–78. https://doi.org/10.2307/2889

Spinage CA (1972) African ungulate life tables. Ecology 53:645–652. https://doi.org/10.2307/1934778

Vaupel JW, Baudisch A, Dölling M et al (2004) The case for negative senescence. Theor Popul Biol 65:339–351. https://doi.org/10.1016/j.tpb.2003.12.003

Wikipedia, entry List of world records in masters athletics (consulted on 13/09/2018), data from various sources, https://en.wikipedia.org/wiki/List_of_world_records_in_masters_athletics

Williams GC (1957) Pleiotropy, natural selection and the evolution of senescence. Evolution 11:398–411. https://doi.org/10.1111/j.1558-5646.1957.tb02911.x

Wodinsky J (1977) Hormonal inhibition of feeding of death in octopus. Control by optic gland secretion. Science 198:948–951. https://doi.org/10.1126/science.198.4320.948

Woo HR, Masclaux-Daubresse C, Lim PO (2018) Plant senescence: how plants know when and how to die. J Exp Bot 69(4):715–718. https://doi.org/10.1093/jxb/ery011