ferences between the sexes. Generally, the smaller sex lives longer. In mice, reduced growth hormone and insulin-like growth factor (IGF) activity reduces size and increases longevity (*11*), so perhaps a similar mechanism is working here.

Reinke *et al.* focus on other hypotheses about variables that affect the rate of aging, comparing the slow turtle senescence with that of other groups. For example, environmental temperature correlated negatively with aging rates of reptiles, as expected from the slowing of metabolism in ectotherms with decreasing environmental temperature. However, this correlation was reversed in amphibians, a finding that deserves some mechanistic follow-up. Among all terrestrial vertebrate groups, turtles had the slowest rate of aging—more than 20-fold slower than that of mammals and twice as slow as that of birds and humans. Notably, the tuatara—a 1- to 2-kg reptile that lives on islands off New Zealand—was found to have a 90% slower aging rate than that of turtles in general and a mean lifespan of 137 years. If confirmed, tuataras would be the longest-lived terrestrial vertebrate.

> **"It is clear that ectothermic and endothermic vertebrates vary greatly in their aging rates..."**

Overall, these studies suggest that ectothermic tetrapods generally, and turtles in particular, age very slowly, if at all. However, there are some limitations of these data. If basal mortality rates are high—such as what might happen in zoos, where husbandry for a species may not be optimal—life expectancy can be short even with no increase in mortality with age. This is true of much of the data from da Silva *et al.*: Despite no age-related increase in mortality, most turtle life expectancies are just 10 to 20 years, in spite of reliable records of much longer-lived individuals in those species. Indeed, for seven species, mean life expectancy is shorter than the age at first reproduction. The longest-lived of zoo species is the male Aldabra tortoise, with a mean life expectancy of 55.5 years, which is lower than that of humans in high-income countries. Field data on 14 chelonian species from Reinke *et al.* indicate mean life expectancy is much longer: 39 years, measured from age at first reproduction until 95% of the animals had died.

Another limitation, inherent in mortality rate analysis for nearly any species other than humans, is the paucity of individuals at truly advanced ages, where mortality rate could show acceleration. One analysis of mortality rates showed that most laboratory animal studies lacked sufficient numbers of older individuals to assess whether mortality rate was increasing at later ages (*12*). Calculations indicate that the naked mole rat, a mouse-size rodent with very slow aging, would require a population far larger than the current 3300 individuals to detect late-life mortality acceleration (*13*).

It is clear that ectothermic and endothermic vertebrates vary greatly in their aging rates, despite their fundamentally similar cytological and biochemical architectures (see the figure). By investigating the nature of that variation, something new may be learned about aging in humans. If some species truly escape aging, and mechanistic studies may reveal how they do it, human health and longevity could benefit. The naked mole rat is being scrutinized, but no distinct process has been discovered. Even if many of these fascinating species lack significantly increasing mortality with age, some clearly incur infirmities of aging. Diseases of aging, such as cataracts and various cancers, are well known in chelonians. Harriet, a famous Galápagos tortoise that spent her last years in the Australia Zoo, reputedly lived 170 years, but in the end, she died from a heart attack, a well-known malady of human aging. And the oldest living terrestrial animal, Jonathan—an Aldabra tortoise that has allegedly lived on Saint Helena Island since 1882 and therefore may be 160 to 190 years old (birth date was estimated)—is now blind, has lost his olfactory sense, and must be fed by hand. Demography does not always perfectly reflect physiological decline, particularly in highly protected environments like zoos. So whatever the demography of that species suggests, these ancient tortoises clearly have aged. Thus, the observed longevity may not always correlate with the aging rate. ■

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ENVIRONMENTAL SCIENCE

The delicate balance of river sediments

Global satellite data quantify changes in sediment flux in 414 rivers

By **Christiane Zarfl**[1] *and* **Frances E. Dunn**[2]

Rivers are more than just streams of water; they also carry sediments from the land, riverbeds, and riverbanks and deposit them downstream or into oceans. Sediments play a pivotal role in defining river morphology on small scales (such as riverine habitats) and large scales (such as river deltas), as well as in shaping river ecosystems by transporting nutrients and pollutants. Most anthropogenic land use often increases sediment erosion and transport, whereas dam building decreases sediment transport. In addition, changes in precipitation frequency and intensity—related to climate change—also affect sediment erosion and discharge dynamics. Data concerning these drivers are often lacking but are essential for effective river basin management. On page 1447 of this issue, Dethier *et al.* (*1*) present an analysis of sediment flux changes for 414 rivers worldwide based on satellite data from 1984 to 2020, evaluated against 130,000 field measurements.

In situ characterization of rivers is often lacking because it is too expensive to sample frequently enough to capture important dynamics across large areas. Remote sensing based on satellite or aircraft data has the potential to make environmental monitoring easier by providing access to observations regardless of remoteness or terrain difficulty. Dethier *et al.* used algorithms to derive fluvial—instream—suspended sediment concentrations from global satellite imagery dating back to the 1980s. Although similar techniques have been used locally before [for example, (*2*)], the scale, both spatial and temporal, and extensive verification of the work by Dethier *et al.* is unprecedented, which allows the most detailed and comprehensive analysis of these trends in the data. Overall, they found a

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global reduction in sediment fluxes of almost 50% in rivers located in the Northern Hemisphere, which was mainly the result of sediment entrapment by dams, but an increase in suspended sediment concentrations of over 40% in rivers located in the Southern Hemisphere, which was driven by deforestation and subsequent mining and agricultural activities.

Earlier studies have hinted at the different facets of these findings. Dams and reservoirs are known to be very efficient retention factors, stopping an estimated 50% of sediments that would otherwise be discharged into the oceans (*3*). Because of an expansion of dams—not only for electricity production but also for flood control, irrigation purposes, or water storage—there has been a global decrease in fluvial sediment fluxes (*4*, *5*). This development is spatially heterogeneous both in trend and quantity. For example, recent modeling of cumulative sediment retention by dams on the Mekong River shows that as little as 4% of the total sediment load is expected to reach the river delta (*6*). At the same time, human activities such as agriculture, land leveling, mining, and infrastructure construction increase erosion rates by orders of magnitude (*7*)—far more than the decrease caused by dams. For example, in the Middle Ages, soil erosion increased by up to a hundredfold after deforestation in Europe, as observed in lake sediment core samples (*8*), and it is estimated that more than 50% of the world's ice-free land area has been altered by 2007 from anthropogenic activities (*9*). Understanding and disentangling the natural and anthropogenic drivers of sediment erosion and the accumulation of sediments remains a highly relevant topic in geologic and environmental sciences (*10*).

Changes in sediment fluxes have huge ramifications for the stability of river systems, their geomorphology, ecology, and the socioeconomic activities that rely on their integrity (see the figure). Increased sediment fluxes can cause deposition in river channels. This has many consequences, including changing species composition and ecosystem productivity by altering habitats, increasing flood risk by reducing channel capacity, and creating economic burdens by requiring dredging, such as in reservoirs to maintain storage capacity (*11*) or in river channels to maintain the navigable depth for ships (*12*). Decreased sediment fluxes in so-called "sediment-starved" water can worsen erosion in river channels, destroying ecosystems and aquatic productivity, potentially leading to changes in food webs, nutrient transfer, and even a reduction in biomass formation and threats to food security of local human populations. Sediment-starved water eroding in river channels can also lead to bank collapse, affecting river engineering and land adjacent to rivers and wrecking geomorphic features such as deltas (*13*) and beaches.

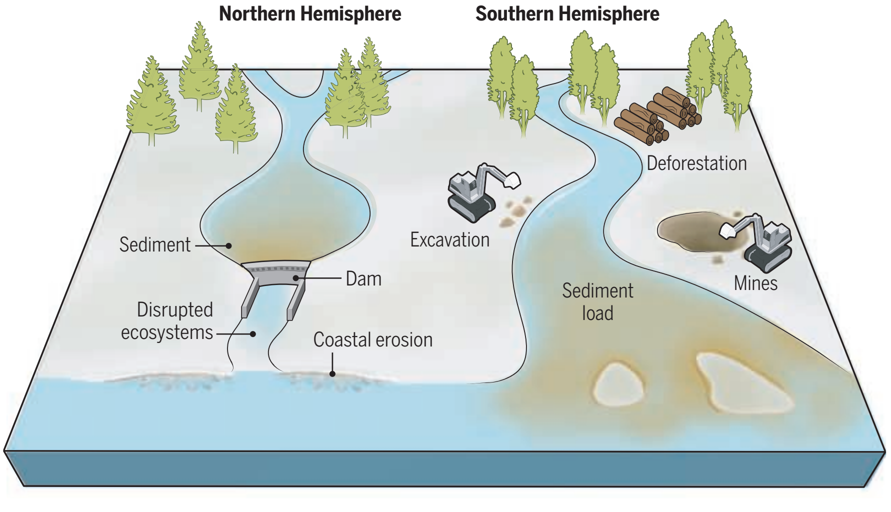
To maintain the physical environment and ensure sustainable use of these systems, these changes must be acknowledged and anticipated to avoid inappropriate decisions that fail to address environmental challenges or that exacerbate unwanted environmental changes. Management decisions must be well informed by data and not by outdated assumptions about the state of river systems, especially given the accelerating rates of change driven by human activities (*14*).

Appropriate management will depend on anticipating future trends, which relies on understanding the key drivers of change. Although projections of fluvial sediment delivery show a continuation of the global decline with some spatial variation (*15*), future data and analyses will contribute to refining projections, particularly for areas of the world where data have been sparse. Historical data can provide information on previously understudied areas and help inform future geoengineering projects based on lessons learned. For example, if fluvial sediment concentrations have recently fallen because of dam construction on the river and more dams are planned, they will not have the same effect as dam construction on a river with no prior dams because sediment concentrations are unable to fall as far. Alternatively, if sediment fluxes have recently increased because of erosion caused by land-use change, the new higher sediment fluxes may be unsustainable and vulnerable to reduction.

Integrated studies that combine new approaches to data mining, such as evaluating satellite data against a set of spatially broad and temporally long monitoring data from the field, can help identify overarching and general patterns in environmental dynamics. Understanding the underlying processes and interdependencies is essential to narrow down the range of potential future developments—that is, to specify scenarios for model projections. This, collectively, is required to provide a sound scientific basis for responding to fluvial sediment flux changes, including the consideration and communication of uncertainties when fostering transparent discussions on sustainable river management. ■

The imbalance of sediment flux between the Northern Hemisphere and Southern Hemisphere

A meta-analysis of 414 major rivers around the world reveals how different human activities affect sediment transport in rivers, and that the Northern and Southern Hemispheres experience problems related to excess retention and erosion of sediment, respectively.



GRAPHIC: N. DESAI/SCIENCE

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