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How do annelids contribute to ecosystem balance?

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Abstract

Annelids are major contributors to ecological stability in terrestrial, freshwater, and marine systems. Their activities influence soil formation, nutrient cycling, sediment turnover, water quality, and trophic dynamics. Earthworms and relatives (Clitellata: Polychaeta, Oligochaeta, and Hirudinea) act as primary agents of bioturbation in soils (Darwin, 1881; Edwards and Bohlen, 1996) [8, 13], while polychaetes dominate benthic processes in marine sediments (Fauchald and Jumars, 1979; Kristensen, 2001) [17, 28]. Through feeding, burrowing, and cast production, annelids regulate microbial communities, enhance nutrient availability, and modify habitats in ways that support biodiversity (Lavelle *et al.*, 1997) [31]. This article reviews the principal ecological functions of annelids and their roles as ecosystem engineers across major habitat types.

Keywords: Annelida, Oligochaeta, Hirudinea, Polychaeta, Bioturbation, Nutrient cycling, Soil structure, Benthic ecology, Ecosystem engineers

Introduction

The phylum Annelida comprises more than 17,000 described species distributed across terrestrial, freshwater, and marine environments (Rouse and Pleijel, 2001) [46]. This diversity reflects a long evolutionary history and a body plan that is both conservative and highly adaptable. The defining features of annelids—metameric segmentation, chaetae, a hydrostatic skeleton, and a wide array of feeding structures enable them to occupy ecological niches ranging from deep sea hydrothermal vents to temperate forest soils. Segmentation allows regional specialization of musculature and organ systems, supporting efficient burrowing, locomotion, and resource acquisition across heterogeneous substrates.

Annelids influence ecosystem processes at multiple spatial and temporal scales. At the microscale, their feeding and digestive activities regulate microbial assemblages and accelerate the breakdown of organic matter, thereby driving nutrient mineralization and turnover. At broader scales, the cumulative effects of burrowing, cast deposition, and sediment reworking contribute to soil formation, sediment stability, and biogeochemical cycling. These processes shape the physical structure of habitats and influence the distribution and abundance of other organisms.

The ecological significance of annelids has been recognized since Darwin's foundational work on earthworms and soil turnover, which demonstrated their capacity to modify landscapes through continuous bioturbation (Darwin, 1881) [8]. Subsequent research has expanded this understanding to include the roles of polychaetes in marine sediment dynamics, where they function as dominant benthic engineers. Polychaete feeding guilds—ranging from deposit feeders to active predators—mediate the flow of energy and nutrients through benthic food webs (Fauchald & Jumars, 1979) [17]. Their burrowing and ventilation activities alter redox gradients, enhance oxygen penetration, and regulate microbial processes within sediments (Kristensen 2001) [28].

Across ecosystems, annelids serve as key intermediaries linking detrital pathways, microbial processes, and higher trophic levels. Their capacity to modify substrates, regulate nutrient availability, and support diverse biological communities underscores their importance as ecosystem engineers. Understanding the breadth of their ecological roles is essential for interpreting patterns of biodiversity, productivity, and environmental change in both terrestrial and aquatic systems.

Structural and Functional adaptations

Annelids possess a metameric body plan in which the body is divided into serially repeated segments, each containing paired coelomic compartments, musculature, excretory organs, and elements of the circulatory and nervous systems. This organization provides both structural redundancy and functional flexibility. Segmentation allows localized control of movement, enabling annelids to generate peristaltic waves, anchor specific body regions, and exert fine scale mechanical force on substrates. The hydrostatic skeleton formed by fluid filled coeloms provides rigidity against which circular and longitudinal muscles act, permitting efficient burrowing, crawling, and swimming.

Polychaetes exhibit the greatest morphological diversity within the phylum. Their parapodia paired, lateral appendages bearing bundles of chaetae serve as locomotory paddles, respiratory surfaces, and anchoring structures. Many polychaetes possess highly specialized feeding appendages, including eversible pharynges armed with jaws, grooved palps for selective deposit feeding, and elaborate radiolar crowns used in suspension feeding (Fauchald and Jumars, 1979)[17]. These adaptations support a broad spectrum of trophic strategies, allowing polychaetes to function as predators, scavengers, deposit feeders, or filter feeders depending on habitat and lineage. The diversity of polychaete feeding guilds contributes significantly to benthic energy flow and nutrient regeneration.

Clitellates, which include earthworms and leeches, lack parapodia and show a more compact external morphology. Their defining feature, the clitellum, secretes cocoons that protect developing embryos and facilitate direct development without a pelagic larval stage. Earthworms exhibit a suite of adaptations for life within soil matrices (Figure 1): reduced chaetae that anchor segments during peristaltic movement, reinforced longitudinal musculature for substrate penetration, and a streamlined body that minimizes resistance in compact mineral soils (Edwards and Bohlen, 1996) [13]. Their integument is highly vascularized and kept moist to facilitate cutaneous respiration, an essential requirement for subterranean life. Many species also possess calciferous glands that regulate internal pH and influence the chemistry of ingested soil.

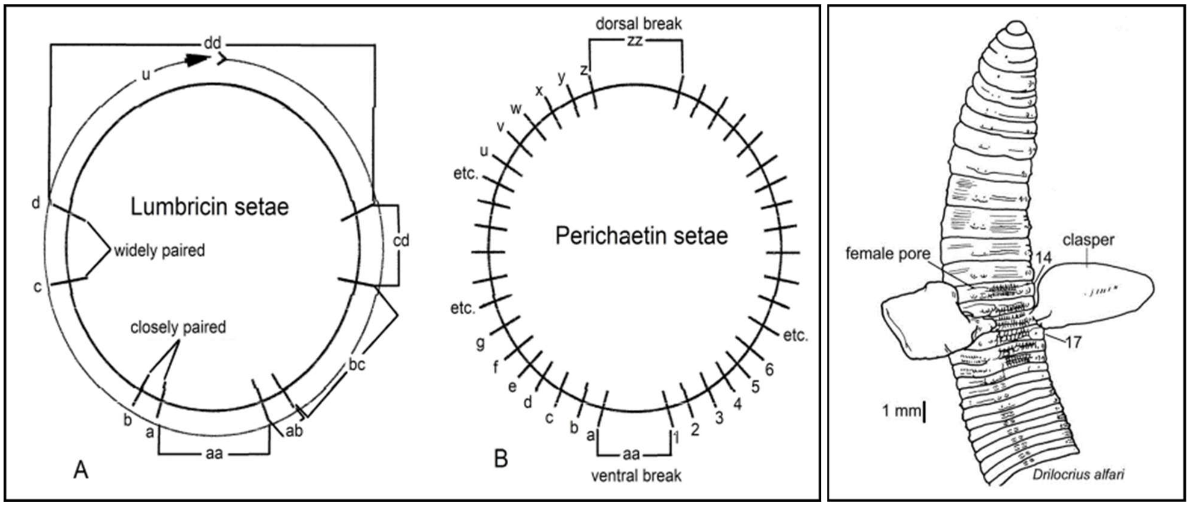


Fig 1: (left) **B** perichaetin(e) setae permit species in Megascolecidae to move on all surfaces, not just the ventral surface like those with the lumbricin(e) arrangement; (right) claspers in *Drilocrius alfari* (Almididae) developed for securing partner during reproduction (from Reynolds, 2026) [46]

These structural features collectively underpin the ecological versatility of annelids. Their capacity for efficient locomotion, substrate modification, and exploitation of diverse food resources allows them to occupy key functional roles in both terrestrial and aquatic ecosystems. By altering sediment structure, regulating microbial processes, and influencing nutrient availability, annelids act as ecosystem engineers whose activities shape the physical and biological characteristics of the habitats they inhabit.

Roles in Terrestrial Ecosystems

Earthworms are the dominant annelids in terrestrial environments and exert disproportionate influence on soil structure, chemistry, and biological activity. Their ecological roles arise from a combination of burrowing behaviour, feeding strategies, and continuous processing of organic and mineral substrates. These activities collectively define them as major bioturbators and ecosystem engineers in temperate and tropical soils.

Soil Formation and Bioturbation

Earthworm burrowing alters the physical architecture of soils at multiple scales. Horizontal and vertical galleries increase porosity, enhance aeration, and facilitate the downward movement of organic matter and surface litter. The mechanical action of burrowing breaks apart compacted horizons and promotes the formation of stable soil aggregates. These aggregates, bound by mucus and microbial by products, contribute to long term soil development and improved structural stability. Darwin's early observations demonstrated that the cumulative effects of earthworm activity can alter entire landscapes over centuries, gradually incorporating surface material into deeper horizons and generating fine, well mixed topsoil (Darwin, 1881)[8]. Modern studies confirm that earthworms remain among the most effective natural agents of soil turnover (Edwards and Bohlen, 1996) [13].

Feeding, Digestion, and Nutrient Cycling

Earthworms ingest a mixture of mineral particles, organic detritus, and associated microorganisms. During digestion, organic matter is fragmented and exposed to enzymatic and microbial processes that accelerate decomposition. Casts produced at the soil surface and within burrows typically contain elevated concentrations of plant available nutrients, including ammonium, nitrate, and soluble phosphorus. These nutrient rich casts form microsites of high fertility that influence root distribution and microbial colonization. The continual deposition of casts contributes to nutrient heterogeneity within soils, supporting diverse microbial and plant communities. Earthworm activity also enhances nitrogen mineralization rates and can influence carbon sequestration dynamics through the stabilization of organic matter within aggregates (Lavelle *et al.*, 1997) [32].

Influence on Hydrology and Root Dynamics

The burrow systems created by anecic and endogeic earthworms act as preferential flow paths for water infiltration. These channels reduce surface runoff, increase water storage capacity, and improve the resilience of soils to drought and heavy rainfall. Roots frequently exploit abandoned burrows, benefiting from improved aeration and access to nutrient rich cast material. The interaction between earthworm burrows and root systems enhances plant growth and contributes to the overall productivity of terrestrial ecosystems.

Interactions with Soil Biota

Earthworms interact extensively with soil microorganisms, arthropods, and other invertebrates. Their feeding activities regulate microbial community composition by selectively ingesting fungal hyphae, bacteria, and protozoa. Burrows provide microhabitats for mites, collembolans, nematodes, and other small invertebrates, increasing habitat complexity and supporting higher biodiversity. Through these interactions, earthworms influence trophic dynamics and energy flow within soil food webs.

Functional Groups and Ecological Roles

Earthworms are commonly classified into ecological groups epigeic, endogeic, and anecic each contributing differently to soil processes (Figure 2).

Epigeic species inhabit surface litter and accelerate decomposition.

Endogeic species burrow within mineral soil and contribute to aggregate formation and nutrient mixing.

Anecic species create deep vertical burrows that connect soil horizons and transport organic matter downward.

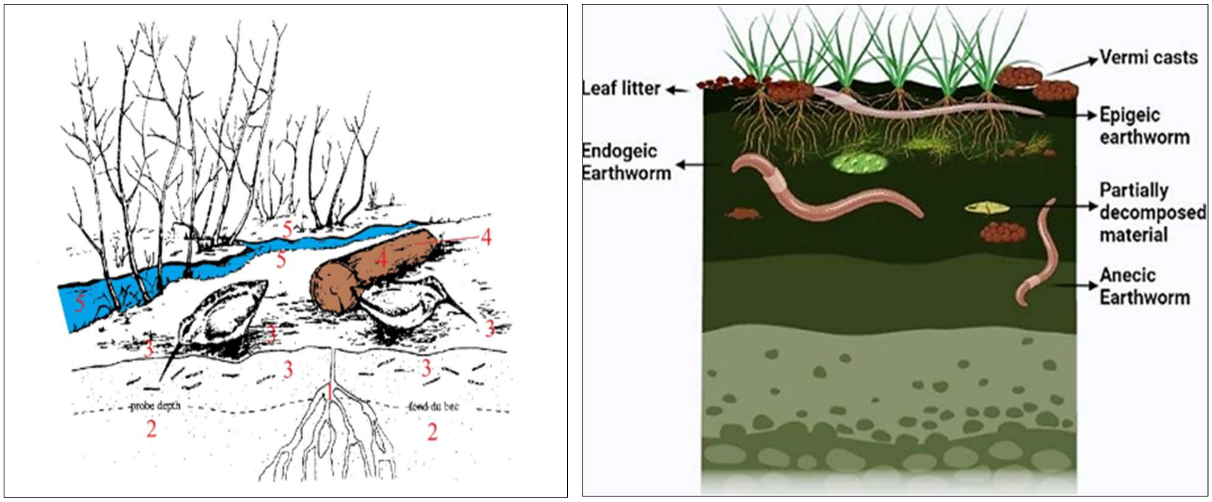


Fig 2: (Left) The location of the earthworm ecological types: 1 = anecic/anécique, 2 = endogeic/endogée, 3 = epigeic/épigée, 4 = corticole/corticole; and 5 = limicolous/limicoles (*modified from* Reynolds, 1977)[43]; (right) (from Sharma, 2022)[49].

Interactions with Soil Biota

Earthworms interact extensively with soil microorganisms, arthropods, and other invertebrates (Figure 3). Their feeding activities regulate microbial community composition by selectively ingesting fungal hyphae, bacteria, and protozoa. Burrows provide microhabitats for mites, collembolans, nematodes, and other small invertebrates, increasing habitat complexity and supporting higher biodiversity. Through these interactions, earthworms influence trophic dynamics and energy flow within soil food webs (Figure 4).

The combined activities of these groups create a vertically integrated system of bioturbation and nutrient redistribution that is central to soil functioning.

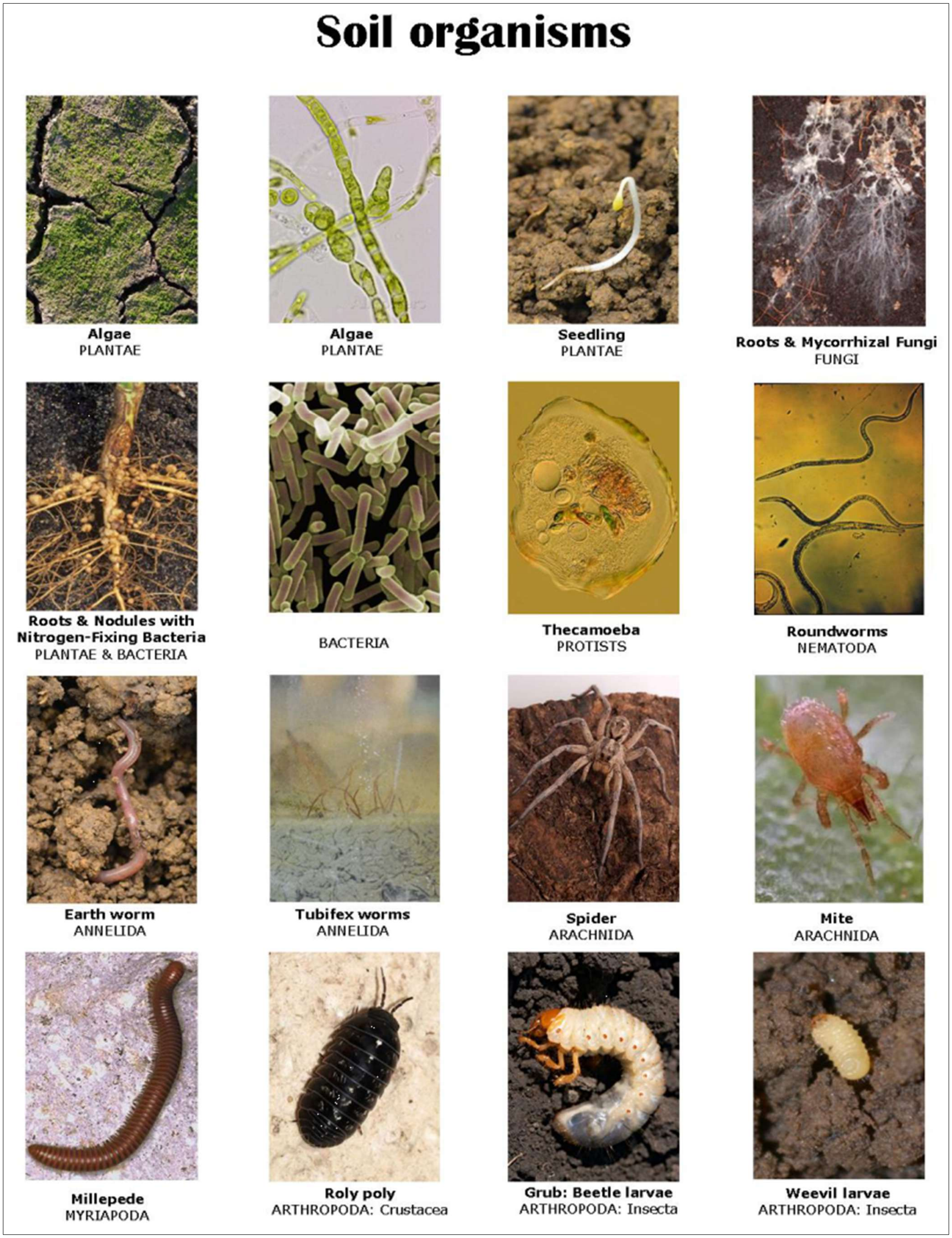


Fig 3: Variety of Organisms living in the soil.

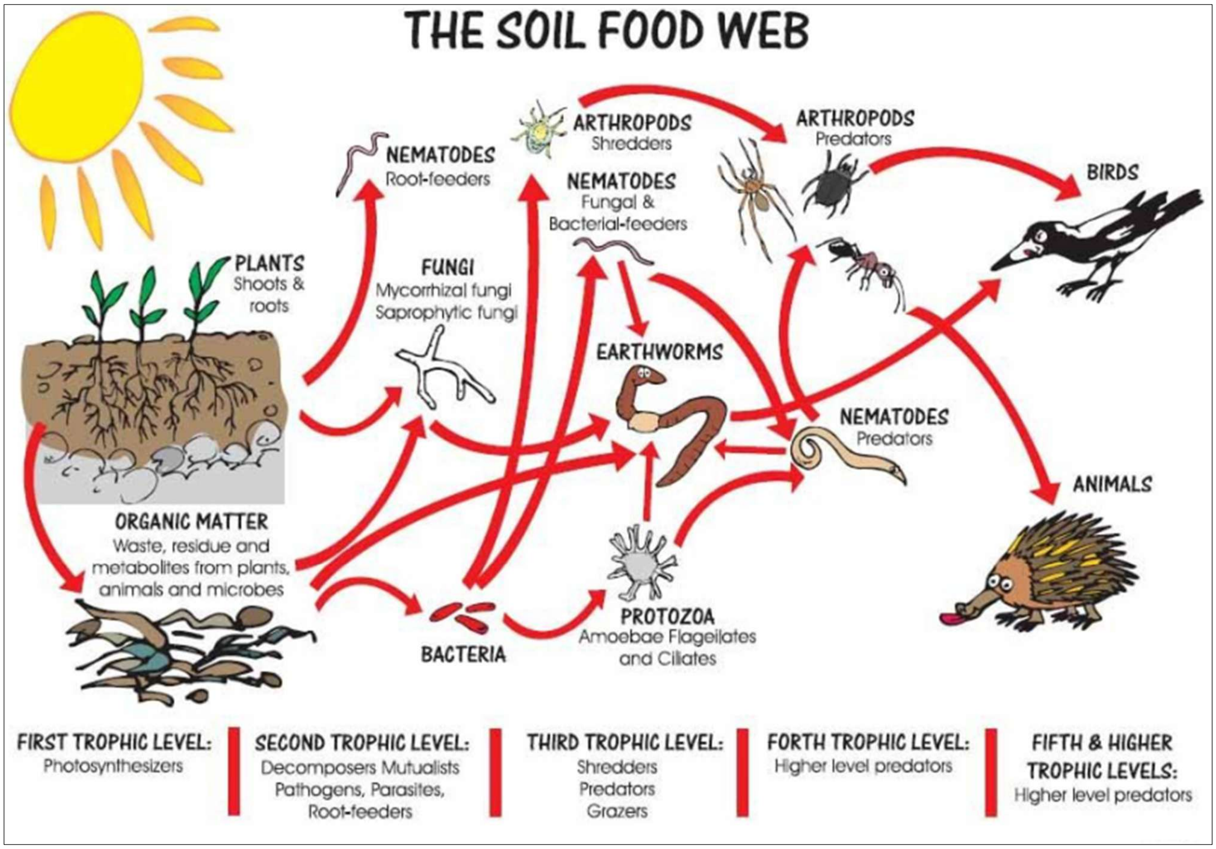
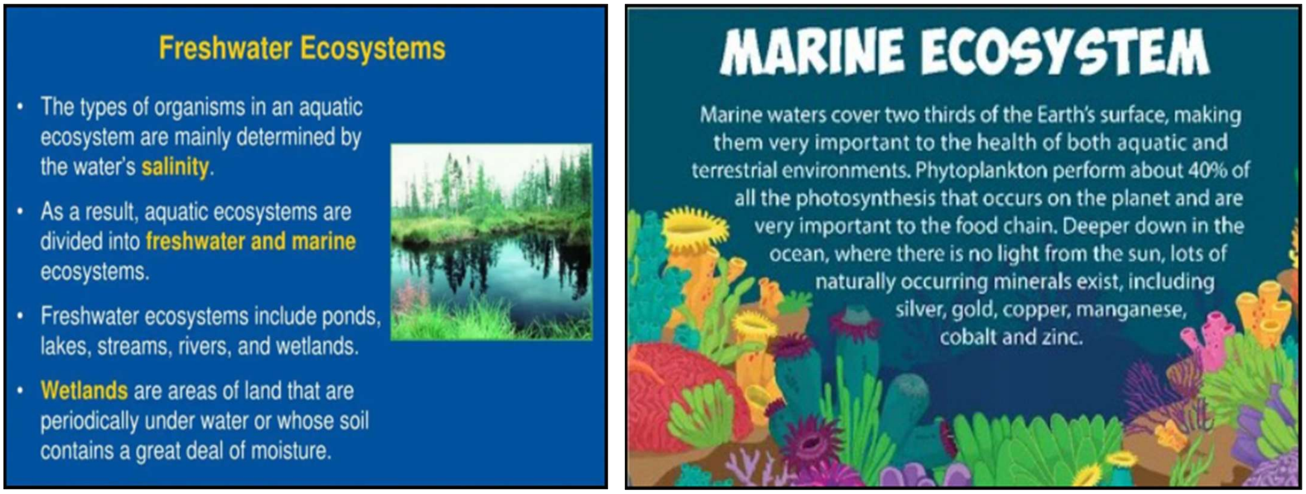


Fig 4: A diagram of the Soil Food Web.

Roles in Marine and Freshwater Ecosystems

Polychaetes and aquatic oligochaetes dominate many benthic communities and are central to the functioning of soft sediment habitats. Their ecological influence arises from the combined effects of burrowing, tube building, feeding, and sediment ventilation. These activities regulate biogeochemical processes, shape habitat structure, and support trophic interactions across marine and freshwater systems (Figure 5).



Freshwater Ecosystems

- The types of organisms in an aquatic ecosystem are mainly determined by the water's **salinity**.
- As a result, aquatic ecosystems are divided into **freshwater and marine** ecosystems.
- Freshwater ecosystems include ponds, lakes, streams, rivers, and wetlands.
- **Wetlands** are areas of land that are periodically under water or whose soil contains a great deal of moisture.

MARINE ECOSYSTEM

Marine waters cover two thirds of the Earth's surface, making them very important to the health of both aquatic and terrestrial environments. Phytoplankton perform about 40% of all the photosynthesis that occurs on the planet and are very important to the food chain. Deeper down in the ocean, where there is no light from the sun, lots of naturally occurring minerals exist, including silver, gold, copper, manganese, cobalt and zinc.

Fig 5: Freshwater and Marine Ecosystems**.**

Sediment Turnover and Benthic Engineering

Burrowing polychaetes such as Arenicolidae, Maldanidae, and Capitellidae are among the most important bioturbators in marine sediments. Their feeding and ventilation behaviours rework large volumes of sediment, altering its physical and chemical properties. As polychaetes move through the substrate, they transport particles vertically and horizontally, disrupt stratification, and enhance the mixing of organic and mineral fractions. Ventilation of burrows introduces oxygenated water into deeper sediment layers, modifying redox gradients and stimulating microbial activity (Kristensen 2001) [28]. These changes influence nutrient fluxes, organic matter degradation, and the distribution of meiofauna and bacteria.

Tube building polychaetes, including Sabellidae, Serpulidae, and Spionidae, create rigid or semi rigid structures that protrude from the sediment surface. These tubes alter boundary layer flow, trap suspended particles, and stabilize sediments. Dense tube mats can form complex three-dimensional habitats that support diverse assemblages of epifauna and juvenile invertebrates. By modifying hydrodynamic conditions and substrate stability, tube builders act as ecosystem engineers whose structures influence community composition and sediment dynamics.

Biomonitoring Indicators and Environmental Assessment

Annelids, particularly oligochaetes and polychaetes, are highly sensitive to environmental changes, making them effective bioindicators of soil and water quality. They respond to pollution, eutrophication, heavy metal contamination, and hypoxia in predictable ways (Reynolds, 1994; Dean, 2008; Hasan *et al.*, 2026) [9, 22, 44].

Freshwater Oligochaetes: Tubificidae and Naididae species are used in assessing organic pollution in rivers, lakes, and wetlands. Species composition and abundance patterns correlate with nutrient levels and oxygen availability (Timm, 1984; Martins *et al.*, 2008) [37, 53].

Marine Polychaetes: Families such as Capitellidae, Spionidae, and Maldanidae dominate organically enriched sediments and are incorporated into indices like AMBI (AZTI Marine Biotic Index) for monitoring benthic health (Borja *et al.*, 2000)[5].

Leeches: Hirudinea are employed as indicators of freshwater ecosystem integrity, as certain species require pristine, oxygen-rich habitats (Borda and Siddall, 2004) [4].

These applications demonstrate the dual role of annelids as functional ecosystem engineers and environmental sentinels, providing crucial data for conservation and management.

Feeding Strategies and Nutrient Regeneration

Polychaetes exhibit a wide range of feeding modes, each contributing differently to nutrient cycling. Deposit feeders (*e.g.*, lugworm, *Abarenicola pacifica* Healy and Wells, 1959)[23] ingest sediment and organic detritus, fragmenting material and enhancing microbial decomposition. Suspension feeders (*Spiochaetopterus oculatus* Webster, 1879 [56] and *Spio setosa* Verrill, 1873)[54] are documented facultative suspension feeders that coil their palps to capture suspended phytoplankton and particulate organic matter from the water column, transferring pelagic production to the benthos. Predatory polychaetes (*e.g.*, bobbit worm, *Eunice aphroditois* (Pallas, 1788)[42]) regulate populations of smaller invertebrates and influence trophic interactions within benthic food webs (Fauchald & Jumars 1979)[18]. Through these feeding activities, polychaetes accelerate nutrient regeneration and release dissolved nutrients that support primary producers such as benthic microalgae.

Freshwater oligochaetes, including Tubificidae and Naididae, play similar roles in lakes, rivers, and wetlands. Their burrowing and feeding activities increase sediment permeability, stimulate microbial processes, and contribute to the breakdown of organic matter. In nutrient rich or polluted environments, oligochaete densities may increase dramatically, making them useful indicators of sediment quality and oxygen conditions.

Contribution of Annelids to Food Web Structure

Annelids occupy pivotal trophic positions in both terrestrial and aquatic ecosystems, functioning simultaneously as consumers of organic matter and as essential prey for higher trophic levels (Reynolds, 2021)[45]. Earthworms, in particular, form a major component of the diet of numerous vertebrates, including birds (*Turdus migratorius* L., 1766 [35]; *Scolopax minor* Gmelin, 1879)[20], small mammals such as shrews (*Talpa europa* L., 1758)[34], amphibians (*Desmognathus fuscus* Green, 1818)[21], reptiles (*Thamnophis sirtalis pallidulus* Allen, 1899)[1], and many freshwater fish species (Dindal, 1970; Skoczeń, 1970; Reynolds, 1977; McAlpine *et al.*, 2019) [10, 38, 43, 52]. They are also consumed by a wide range of invertebrate predators (turbellarian, *Bipalium adventitum* Hymen, 1943 [26]; slug, *Testacella haliotidea* Lamarck, 1801) [31], contributing substantially to secondary production in soils and sediments (Curry and Schmidt, 2007; Edwards and Bohlen, 1996) [7, 13]. There is also the example of the reverse, a worm eating fish (*Haplotaxis ichthyophagous*) (Gates, 1971) [19].

In addition to their role as prey, several annelid groups act as predators themselves. Many leeches (Hirudinea) are active predators or ectoparasites of aquatic invertebrates, amphibians, and fish, thereby influencing community composition and energy transfer within freshwater systems (Sawyer, 1986) [48]. Polychaetes in marine environments likewise occupy diverse trophic roles, ranging from detritivores to active carnivores, and often serve as key prey for demersal fish and crustaceans (Fauchald and Jumars, 1979) [17] [(Figure 6).

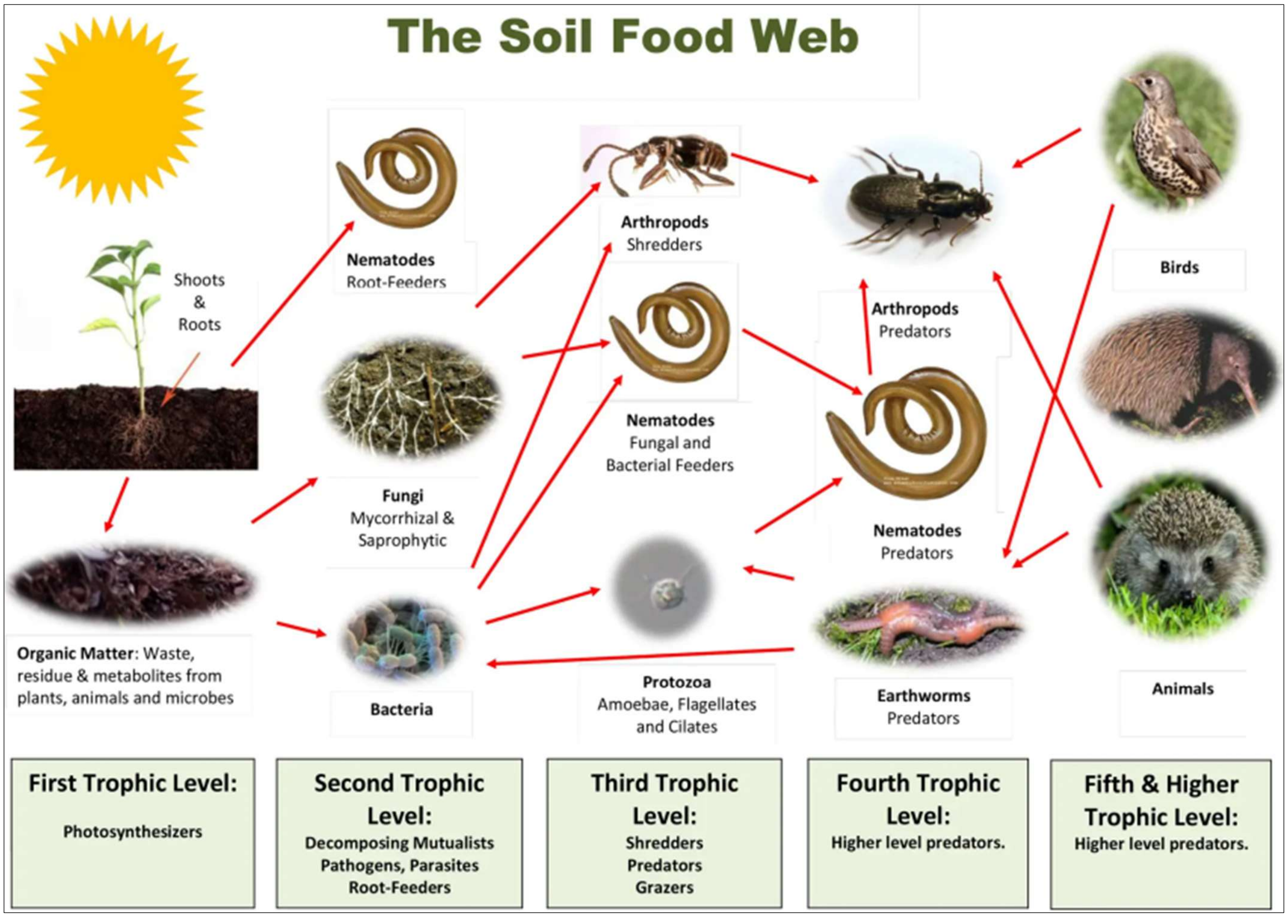


Fig 6: The soil food web indicating the position of earthworms.

By simultaneously processing detritus, mobilizing nutrients, and supporting higher trophic levels, annelids contribute significantly to biodiversity maintenance and energy flow across ecosystems. Their dual roles as consumers and prey make them integral components of soil and benthic food webs, linking microbial processes with vertebrate and invertebrate predators.

Oxygen Dynamics and Biogeochemical Cycling

The ventilation of burrows by polychaetes enhances oxygen penetration into sediments, promoting aerobic decomposition and nitrification. This process increases the efficiency of organic matter degradation and influences the cycling of nitrogen, phosphorus, and sulphur (Figure 7). In many coastal systems, polychaete activity is a major driver of benthic–pelagic coupling, linking sediment processes with water column nutrient dynamics. By regulating oxygen availability and microbial metabolism, polychaetes help maintain sediment health and prevent the accumulation of reduced, anoxic layers.

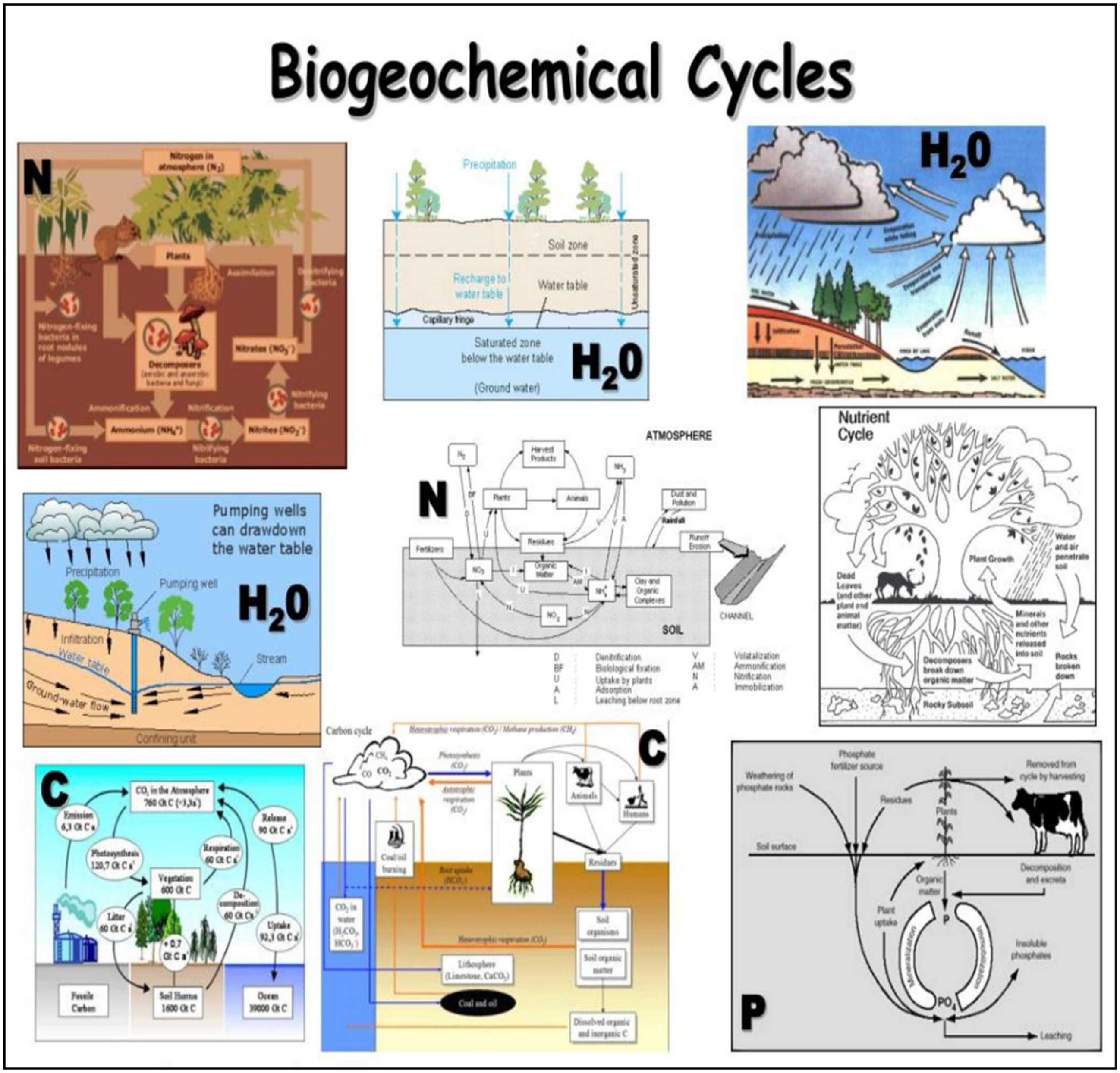


Fig 7: Diagram of several biochemical cycles: C = carbon, N = nitrogen, P - phosphorous, H_2O = water.

Trophic Interactions and Food Web Support

Annelids form a substantial portion of the biomass in many benthic habitats and serve as key prey for fish, crustaceans, shorebirds, and other predators. Their high protein content and abundance make them important intermediaries in energy transfer from detrital and microbial pathways to higher trophic levels. In soft sediment marine environments, polychaetes often dominate invertebrate communities and play a central role in structuring food webs. Seasonal pulses of polychaete recruitment can influence predator behaviour, migration patterns, and reproductive success. Terrestrial Food Web is shown in **Figure 6** including the earthworms' position.

Habitat Modification and Biodiversity Enhancement

Through burrowing, tube building, and feeding, annelids create micro-habitats that support diverse assemblages of microorganisms and small invertebrates. Their activities increase sediment heterogeneity, promote niche differentiation, and influence successional dynamics. In many estuarine and coastal systems, polychaete engineering contributes to the maintenance of species rich benthic communities. The presence or absence of key polychaete taxa can alter community structure, nutrient cycling rates, and overall ecosystem functioning.

Ecosystem Engineering and Biodiversity Support

Annelids function as ecosystem engineers because their routine behaviours burrowing, tube building, feeding, and cast production modify the physical and chemical properties of their environments in ways that influence other organisms. These modifications occur across terrestrial, freshwater, and marine systems, and their cumulative effects shape habitat structure, resource availability, and community composition.

Habitat Modification Through Burrowing and Tube Building

Burrowing annelids alter sediment architecture by creating networks of tunnels and galleries that increase porosity, enhance aeration, and facilitate the movement of water and solutes. In soils, earthworm burrows act as conduits for root growth, microbial colonization, and the movement of organic matter between horizons. In marine sediments, the burrows of polychaetes such as *Arenicola* spp. and *Nereis* spp. introduce oxygenated water into deeper layers, shifting redox boundaries and stimulating microbial processes that would otherwise be limited by anoxia (Kristensen, 2001) [28]. These changes create microhabitats that support diverse assemblages of bacteria, protists, meiofauna, and small invertebrates.

Tube building polychaetes exert a different, but equally significant form of habitat modification. Their tubes—constructed from mucus, sediment particles, or calcareous secretions—stabilize sediments and create vertical structures that protrude into the water column (Figure 6). Dense aggregations of tubes alter hydrodynamic flow, trap suspended particles, and provide attachment surfaces for algae, bryozoans, and juvenile invertebrates. These tube mats increase habitat complexity and promote biodiversity by offering refuge from predators and environmental stressors.

Fig 8: (left) Tube-building annelids, often called "sea worms," and their underwater castles represent one of the most enduring examples of animal architecture on Earth; from the spiral-shaped calcareous tubes of serpulid worms (Serpulidae). (Right) Tube-building polychaete worms first appeared during the early Cambrian period, approximately 540 million years ago (*Riftia pachyptila* Jones, 1981) [27].

Aquaculture and Fisheries Ecosystem Engineering

Several annelid families play crucial roles in aquaculture, fisheries, and habitat engineering (Hasan *et al.*, 2026) [22]:

Polychaetes: Nereididae, Capitellidae, and Arenicolidae species are cultured as live feed for marine fishes and crustaceans in aquaculture, enhancing growth and survival (Fitzhugh and Rouse, 2013)[18]. Bioturbation and sediment stabilization: Burrowing polychaetes and oligochaetes enhance sediment oxygenation and nutrient fluxes in estuaries, mangroves, and aquaculture ponds (Mermillod-Blondin and Rosenberg, 2006) [39].

Leeches in aquaculture: Piscicolid leeches, while sometimes parasitic, also contribute to ecological research and natural control of invasive fish species (Sawyer, 1986) [48].

These applied roles demonstrate the multifunctional importance of annelids across terrestrial, freshwater, and marine systems, linking biodiversity with ecosystem services and human economies.

Influence on Microbial Communities and Biogeochemical Processes

Annelid activity strongly influences microbial community structure. Feeding, burrowing, and ventilation continually expose buried organic matter to oxygen and microbial enzymes, accelerating decomposition and nutrient mineralization. Earthworm casts contain distinct microbial assemblages with elevated enzymatic activity, forming hotspots of nutrient cycling within soils (Lavelle *et al.*, 1997) [32]. In marine sediments, polychaete ventilation enhances aerobic microbial processes while simultaneously supporting anaerobic pathways in adjacent microzones, creating a mosaic of metabolic niches that increase microbial diversity.

These microbial interactions have cascading effects on ecosystem functioning. Enhanced mineralization increases the availability of nitrogen, phosphorus, and other nutrients, supporting primary production in both terrestrial and aquatic systems. By regulating microbial metabolism, annelids influence carbon sequestration, greenhouse gas fluxes, and the long-term stability of organic matter (Figure 9).

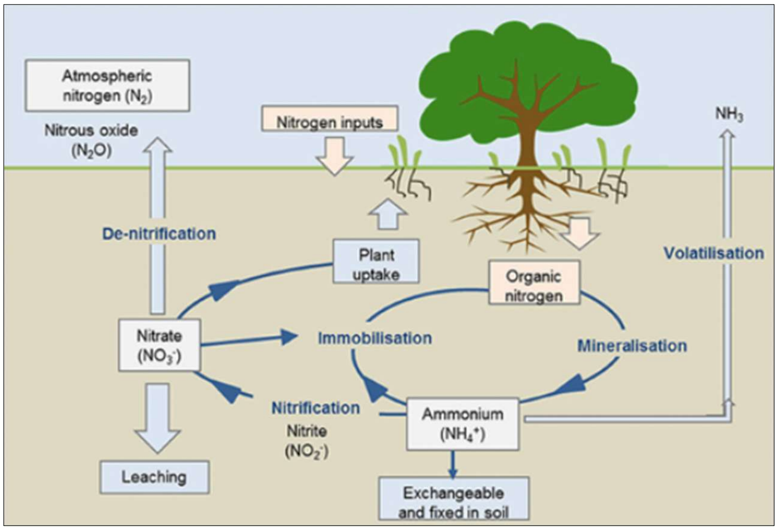


Fig 9: Influence on microbial communities and biogeochemical processes.

Promotion of biodiversity through niche creation

The structural modifications produced by annelids generate ecological niches that support a wide range of organisms. In soils, earthworm burrows (*Aporrectodea longa* (Ude, 1885)[55], *Lumbricus terrestris* L., 1758)[34] provide stable microclimates with moderated temperature and moisture, benefiting arthropods, nematodes, and other soil fauna. Burrow linings enriched with organic matter attract microbial colonizers and serve as feeding sites for detritivores. In marine environments, polychaete tubes and burrows create refuges for juvenile crustaceans, molluscs, and small fish, increasing survival rates and contributing to community resilience. The *Niche UtilizationTheory* states that no two species, can be in the same place, at the same time, doing the same thing, as one will dominate at the expense of the other (Figure 2). In the case of the ecological types of earthworms, they are in the same soil profile, at the same time, but they are doing different things.

These engineered habitats often persist long after the annelids that created them have died or moved, extending their ecological influence across temporal scales. The presence of key annelid species can therefore determine the structure and diversity of entire communities, and their removal can lead to declines in biodiversity and shifts in ecosystem functioning.

Stabilization of ecosystem processes

By modifying sediments, regulating nutrient availability, and supporting diverse biological communities, annelids contribute to the stability and resilience of ecosystems. Their activities buffer environmental fluctuations by improving soil structure, enhancing water infiltration, and maintaining oxygenated microhabitats within sediments. In coastal systems, polychaete tube mats can reduce erosion and increase sediment retention, protecting shorelines and supporting seagrass and algal communities.

Across ecosystems, the engineering effects of annelids promote functional redundancy, increase habitat heterogeneity, and support complex food webs. These contributions underscore their importance as foundational organisms whose presence is essential for maintaining ecological balance (Figure 10).

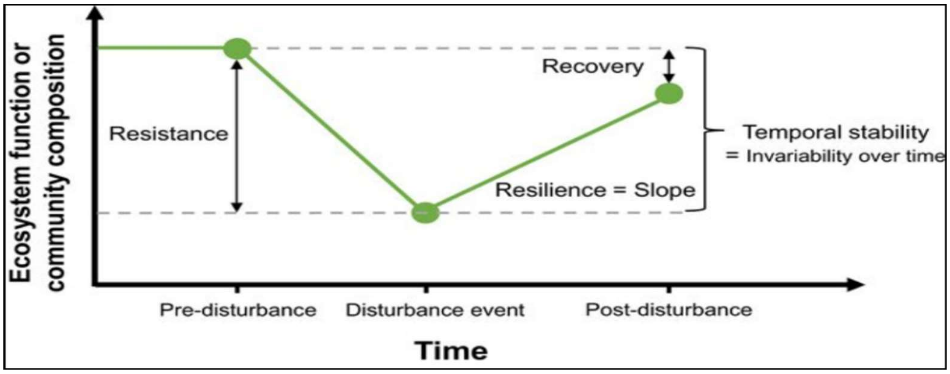


Fig 10: A conceptual diagram of the four dimensions of ecological stability examined in this study. Resistance is defined as the ability to withstand disturbance and quantified as the difference in ecosystem function or community composition between the disturbance year and pre disturbance year. Resilience is defined as the rate of return of ecosystem function or community composition to the pre disturbance state, and quantified as the slope of change following disturbance. Recovery is defined as the extent to which ecosystem function or community composition, following disturbance, returns to its pre disturbance state and quantified as the difference between the post disturbance year and the pre disturbance year. Temporal stability is defined as the degree of constancy of ecosystem function or community composition over time (from Xu *et al.*, 2022) [57].

Ecosystem Engineering and Biodiversity Support

Through burrowing, tube building, and feeding, annelids modify physical and chemical properties of their habitats. These modifications create microhabitats for microorganisms and small invertebrates, increase habitat heterogeneity, and influence successional dynamics (Lavelle *et al.*, 1997) [32]. Earthworm burrows provide refugia for soil arthropods and channels for root growth (Edwards and Bohlen, 1996) [13]. Polychaete tubes stabilize sediments and support epifaunal assemblages (Kristensen, 2001) [28]. Such engineering effects enhance biodiversity and ecosystem resilience (Figure 11).

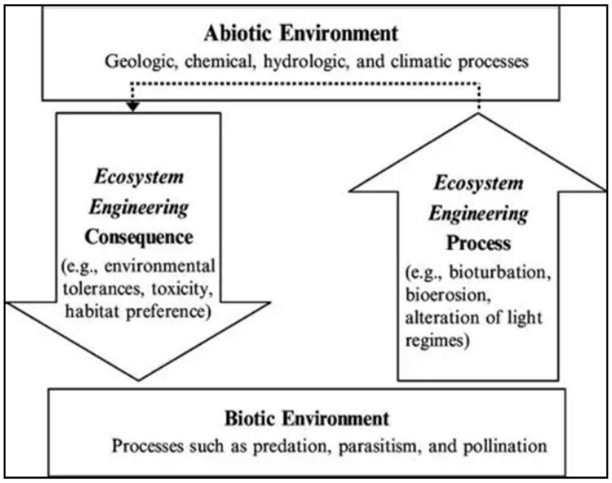


Fig 11: The consequences and processes of ecosystem engineering.

Agricultural and Human Benefits

Earthworms are among the most influential soil invertebrates in agricultural landscapes, where their activities directly affect soil fertility, crop performance, and long-term soil sustainability. Their contributions arise from a combination of bioturbation, organic matter processing, nutrient mineralization, and interactions with plant roots and soil microorganisms. These functions make earthworms central to the concept of soil biological quality, and their presence is widely regarded as an indicator of productive, resilient soils (Edwards and Bohlen, 1996) [13].

According to Hasan *et al.* (2026) [22]: Earthworms (Megadrili and Microdrili) are central to soil health due to their roles in organic matter decomposition, nutrient cycling, and soil structuring. They ingest litter and mineral soil, creating casts that are rich in nitrogen, phosphorus, and other essential nutrients, which enhances plant growth and microbial activity (Edwards and Bohlen, 1996; Blakemore, 2008) [3, 13] (Figure 12).

Soil aeration and porosity: Earthworm burrows improve water infiltration and root penetration. Families such as Lumbricidae, Megascolecidae, and Moniligastridae are highly effective in creating macropores that enhance soil aeration (Lee, 1985) [33].

Organic matter processing: Detritivorous earthworms fragment leaf litter and facilitate microbial decomposition. Tropical regions, including the Western Ghats and Amazon Basin, exhibit exceptionally high biomass of earthworms, highlighting their functional significance in nutrient turnover (Narayanan *et al.,* 2022) [41]. Agricultural applications: Earthworms are widely used in vermicomposting, converting organic waste into nutrient-rich humus, and are recognized as sustainable soil enhancers for crop production (Edwards and Arancon, 2004) [12].

Clitellate diversity is directly linked to soil type, vegetation, and climatic conditions. Regions with high endemic earthworm richness often overlap with biodiversity hotspots, emphasizing the conservation value of soil annelids (Blakemore, 2008) [3].

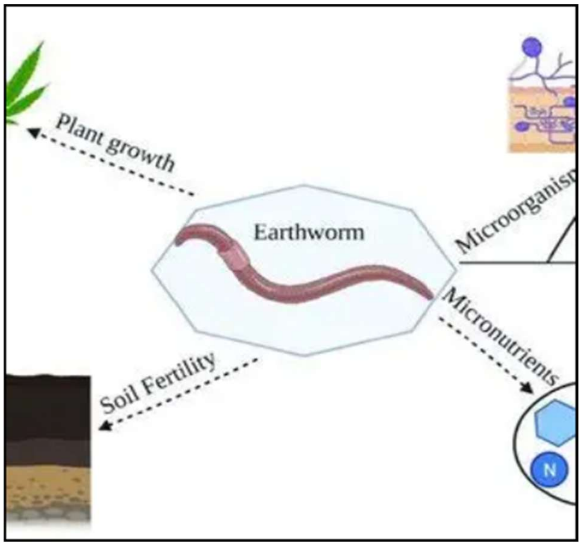


Fig 12: Earthworm's contribution to soil fertility.

Enhancement of soil structure and physical properties

Earthworm burrowing improves the physical condition of agricultural soils by increasing porosity, reducing compaction, and enhancing aggregate stability (Edwards and Bohlen, 1996) [13]. Anecic species (*Aporrectodea longa*, *Lumbricus terrestris*) create deep vertical burrows that act as permanent macropores, facilitating rapid infiltration of rainfall and reducing surface runoff. Endogeic species (*e.g.*, *Aporrectodea tuberculata* (Eisen, 1874) [16]; *Lumbricus rubellus* Hoffmeister, 1843) [25] mix organic and mineral fractions within the soil matrix, producing stable aggregates bound by mucus and microbial by products. These aggregates improve aeration, water retention, and root penetration, all of which contribute to higher crop productivity. In no till and reduced tillage systems, earthworm burrows often become the primary pathways for water movement and root growth, compensating for the absence of mechanical soil loosening (Edwards *et al.*, 1989) [15].

Organic Matter Processing and Vermicomposting

Earthworms accelerate the decomposition of crop residues, manure, and other organic amendments. Their ingestion and fragmentation of organic matter increase its surface area and expose it to microbial enzymes, speeding the conversion of complex materials into humified forms (Lavelle *et al.*, 1997) [32]. Vermi-composting systems (Figure 13) exploit these capabilities by using epigeic species such as *Eisenia fetida* (Savigny, 1826) [47] to convert organic waste into nutrient rich vermicast. Vermicast contains elevated levels of plant available nutrients, beneficial microorganisms, and growth promoting compounds, making it a valuable soil amendment in both conventional and organic agriculture (Edwards *et al.*, 2011; Edwards and Arancon, 2022) [12, 14]. The use of vermicompost can improve seedling vigour, enhance root development, and increase yields across a variety of crops.

Fig 13: A diagrammatical example of a vermi-composting system.

Nutrient Cycling and Fertility Enhancement

Earthworm casts are enriched in nitrogen, phosphorus, potassium, and micronutrients relative to surrounding soil (Edwards and Bohlen, 1996) [13]. These nutrients are present in forms readily accessible to plants, contributing to improved fertility and reduced reliance on synthetic fertilizers. Earthworm activity enhances nitrogen mineralization, promotes the formation of nitrate through microbial pathways, and increases the availability of phosphorus by releasing it from organic complexes (Lavelle *et al.*, 1997) [32]. In cropping systems with high earthworm densities, nutrient turnover rates are significantly elevated, supporting sustained plant growth even under moderate nutrient inputs.

Interactions with Plant Roots and Rhizosphere Processes

Earthworm burrows create favourable microenvironments for root growth by providing aerated channels with high nutrient concentrations (Figure 14). Roots frequently proliferate within these burrows, accessing both moisture and nutrients more efficiently than in surrounding soil (Edwards and Bohlen, 1996) [13]. Earthworm activity also influences rhizosphere microbial communities by transporting microorganisms, altering pH, and modifying the distribution of organic matter. These interactions can enhance nutrient uptake, improve plant stress tolerance, and support beneficial symbioses such as mycorrhizal associations.

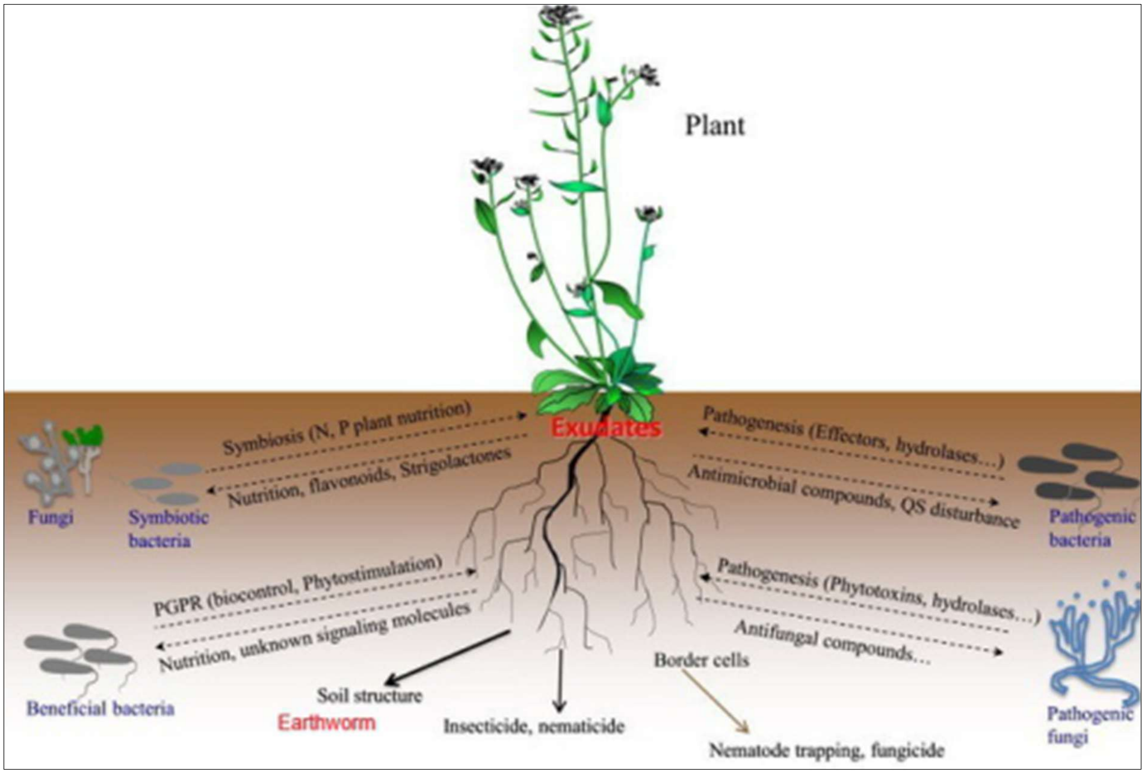


Fig 14: Earthworm interaction with plant roots.

Contribution to Sustainable Agriculture

Earthworms play a central role in sustainable farming practices by reducing the need for mechanical tillage, improving soil structure, and enhancing nutrient use efficiency. Their activities help maintain soil organic matter, reduce erosion, and increase resilience to drought and heavy rainfall (Lavelle *et al.*, 1997) [32]. Conservation tillage, cover cropping, and organic amendments all promote earthworm populations, creating positive feedback loops that improve soil health over time. In agroecosystems where earthworms are abundant, farmers often observe improved crop performance, reduced input requirements, and greater long-term stability of soil functions.

Human uses beyond agriculture

Beyond their agricultural roles, annelids have additional human applications. Earthworms are widely used as bait in recreational fishing and as feed in aquaculture due to their high protein content. Polychaetes, particularly nereidids, are harvested for use in aquaculture hatcheries as a source of essential fatty acids that promote reproductive success in broodstock. In environmental monitoring, freshwater oligochaetes serve as bioindicators of sediment quality, especially in nutrient rich or polluted environments where their densities may increase dramatically (Hendrix *et al.*, 2008) [24].

Medical leech therapy and bioactive compounds

Leeches (Hirudinea) have a long-standing history in medicine, both traditional and modern. Medicinal leeches, particularly *Hirudo medicinalis* L., 1758 [34] and *Hirudo verbana* Carena, 1820 [6], are used in microvascular and reconstructive surgery, promoting blood flow, preventing venous congestion, and enhancing tissue healing (Singh & Bhatnagar, 2011; Kutschera & Elliott, 2014) [28, 51].

Bioactive compounds: Leeches produce anticoagulants (hirudin), anti-inflammatory agents, and anesthetic compounds in their saliva, which have inspired the development of pharmaceuticals (Sawyer, 1986; Kvist *et al.*, 2013) [30, 48].

Parasitology and host studies: Certain leeches act as vectors of blood parasites or as model organisms for studying host-parasite coevolution (Siddall and Borda 2003) [50].

Their ecological and medical significance highlights the intersection between biodiversity, ecosystem function, and human health, emphasizing the need to conserve wild populations and develop sustainable culture methods.

Conclusion

Annelids occupy a central position in the functioning of terrestrial, freshwater, and marine ecosystems. Their influence arises not from a single process, but from the cumulative effects of burrowing, feeding, sediment reworking, and interactions with microbial and plant communities. Across habitats, these activities regulate nutrient availability, modify physical structures, and support diverse assemblages of organisms, making annelids indispensable ecosystem engineers.

In terrestrial systems, earthworms drive soil formation, enhance aggregate stability, and accelerate the decomposition of organic matter. Their burrows improve aeration and hydrological function, while their casts enrich soils with plant available nutrients (Darwin, 1881; Edwards and Bohlen, 1996) [8, 13]. These processes underpin soil fertility and contribute directly to agricultural productivity and sustainability. The engineering effects of earthworms extend beyond nutrient cycling, influencing root architecture, microbial community composition, and the distribution of soil fauna (Lavelle *et al.*, 1997) [32].

In marine and freshwater environments, polychaetes and aquatic oligochaetes perform analogous roles. Burrowing polychaetes rework sediments, alter redox gradients, and stimulate microbial metabolism, thereby regulating biogeochemical cycles (Kristensen, 2001) [28]. Tube building species create complex three-dimensional structures that stabilize sediments and provide habitat for diverse benthic communities. Their feeding strategies—ranging from deposit feeding to active predation—mediate energy flow and nutrient regeneration within benthic food webs (Fauchald & Jumars, 1979) [17]. These contributions are essential for maintaining sediment health, supporting fisheries, and sustaining coastal productivity.

Across ecosystems, the presence of annelids enhances biodiversity by creating microhabitats, increasing substrate heterogeneity, and supporting complex trophic interactions. Their activities buffer environmental fluctuations, promote resilience to disturbance, and maintain the long-term stability of ecological processes. In agricultural and managed landscapes, earthworms contribute to sustainable soil management by reducing the need for mechanical tillage, improving nutrient use efficiency, and supporting crop growth (Bertoncelj *et al.*, 2025)[2].

Taken together, the evidence demonstrates that annelids are foundational to ecosystem balance. Their structural adaptations, behavioural diversity, and ecological versatility allow them to influence processes from the microscale of microbial metabolism to the macroscale of landscape development. Protecting annelid diversity and the habitats they engineer is therefore essential for maintaining the integrity, productivity, and resilience of natural and managed ecosystems.

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References

1. Allen GM. Notes on the reptiles and amphibians of Intervale, New Hampshire. Proc Boston Soc Nat Hist. 1899;29:63–75.
2. Bertoncelj I, Rovanšek A, Leskovšek R. Positive effects of reduced tillage practices on earthworm population detected in the early transition period. Agriculture. 2025;15:1658.
3. Blakemore RJ. *Cosmopolitan earthworms—an eco-taxonomic guide to the peregrine species of the world.* Yokohama: VermEcology; 2008.
4. Borda E, Siddall ME. Arhynchobdellida (Annelida: Oligochaeta: Hirudinida): phylogenetic relationships and evolution. *Mol Phylogenet Evol.* 2004;30(1):213–225.
5. Borja A, Franco J, Pérez V. A marine biotic index to establish the ecological quality of soft-bottom benthos within European estuarine and coastal environments. *Mar Pollut Bull.* 2000;40(12):1100–1114.
6. Carena H. Monographie du genre *Hirudo*. *Mem Reale Accad Sci Torino.* 1820;25:273–316.

7. Curry JP, Schmidt O. The feeding ecology of earthworms: a review. *Pedobiologia.* 2007;50:463–477.
8. Darwin C. *The formation of vegetable mould through the action of earth-worms.* London: Murray; 1881.
9. Dean HK. The use of polychaetes in marine pollution studies. *Rev Biol Trop.* 2008;56(Suppl 4):11–38.
10. Dindal DL. Feeding behavior of a terrestrial turbellarian *Bipalium adventatium*. *Am Midl Nat.* 1970;83(2):635–637.
11. Edwards CA, Arancon NQ. *The science of vermiculture: the use of earthworms in organic waste management.* Boca Raton: CRC Press; 2004.
12. Edwards CA, Arancon NQ, editors. *Biology and ecology of earthworms.* 4th ed. New York: Springer; 2022.
13. Edwards CA, Bohlen PJ. *Biology and ecology of earthworms.* London: Chapman & Hall; 1996.
14. Edwards CA, Arancon NQ, Sherman RL. *Vermiculture technology: earthworms, organic wastes, and environmental management.* Boca Raton: CRC Press; 2011.
15. Edwards WM, Shipitalo MJ, Owens LB, Norton LD. Water and nitrate movement in earthworm burrows within long-term no-till cornfields. *J Soil Water Conserv.* 1989;44(3):240–243. doi:10.1080/00224561.1989.12456320
16. Eisen G. New Englands och Canadas Lumbricider. *Öfvers Kongl Vetensk Akad Forh.* 1874;31(2):41–49.
17. Fauchald K, Jumars PA. The diet of worms: a study of polychaete feeding guilds. *Oceanogr Mar Biol Annu Rev.* 1979;17:193–284.
18. Fitzhugh K, Rouse GW. Polychaetes as aquaculture feed. In: Allan G, Burnell G, editors. Advances in aquaculture hatchery technology. Cambridge: Woodhead Publishing; 2013. p.123–145.
19. Gates GE. On a new species of California earthworm, *Haplotaxis ichthyophagous* (Oligochaeta, Annelida). *Proc Biol Soc Wash.* 1971;84(25):203–212.
20. Gmelin JF. *Scolopax minor.* In: Linnaeus C. *Systema naturae.* 13th ed. Leipzig: Georg Emanuel Beer; 1879. p.661.
21. Green J. Descriptions of several species of North American Amphibia, accompanied with observations. *J Acad Nat Sci Philadelphia.* 1818;1:348–359.
22. Hasan MN, Reynolds JW, Narayana SP, Kosygin L, Mandal CK. Global diversity and taxonomic overview of the Annelida: an integrative review. *Zootaxa.* 2026. (under review).
23. Healy EA, Wells GP. Three new lugworms (Arenicolidae, Polychaeta) from the north Pacific area. *Proc Zool Soc Lond.* 1959;133(2):315–355.
24. Hendrix PF Jr, Callaham MA, Drake JM, Huang CY, James SW, Snyder BA, *et al*. Pandora's box contained bait: the global problem of introduced earthworms. *Annu Rev Ecol Evol Syst.* 2008;39(1):593–613.
25. Hoffmeister W. Beiträge zur Kenntnis deutscher Landanneliden. *Arch Naturgesch.* 1843;9(1):183–198.
26. Hyman LH. Endemic and exotic land planarians in the United States. *Am Mus Novit.* 1943;1241:1–21.
27. Jones ML. *Riftia pachyptila* Jones: observations on the vestimentiferan worm from the Galapagos Rift. *Science.* 1981;213(4505):333–336.
28. Kristensen E. Impact of polychaetes on sediment biogeochemistry. *Oceanogr Mar Biol Annu Rev.* 2001;39:121–167.
29. Kutschera U, Elliott JM. The medicinal leech *Hirudo medicinalis*: historical and contemporary uses. *J Exp Biol.* 2014;217(22):3863–3871.
30. Kvist S, Min GS, Siddall ME. Diversity and selective pressures of anticoagulants in three medicinal leech species. *Mol Phylogenet Evol.* 2013;69(3):659–668.
31. Lamarck JB. *Système des animaux sans vertèbres.* Paris: Detreville; 1801.
32. Lavelle P, Bignell D, Lepage M, Wolters V, Roger P, Ineson P, *et al*. Soil function in a changing world: the role of invertebrate ecosystem engineers. *Eur J Soil Biol.* 1997;33(4):159–193.
33. Lee KE. *Earthworms: their ecology and relationships with soils and land use.* Sydney: Academic Press; 1985.
34. Linnaeus C. *Systema naturae.* 10th ed. Holmiae: Laurentii Salvii; 1758.
35. Linnaeus C. *Systema naturae.* 12th ed. Holmiae: Laurentii Salvii; 1766.
36. Lubbers IM, van Groenigen KJ, Brussaard L, van Groenigen JW. Reduced greenhouse gas mitigation potential of no tillage soils through earthworm activity. *Sci Rep.* 2015;5:13764.
37. Martins RT, Stephan NNC, Alves RG. Tubificidae (Annelida: Oligochaeta) as an indicator of water quality in an urban stream in southeast Brazil. *Acta Limnol Bras.* 2008;20(3):221–226.
38. McAlpine DF, Reynolds JW, Schueler FW. *Thamnophis sirtalis pallidulus* (Maritime garter snake): diet. *Herpetol Rev.* 2019;50(4):815.
39. Mermillod-Blondin F, Rosenberg R. Ecosystem engineering: the impact of bioturbation on biogeochemical processes. *Hydrobiologia.* 2006;56(1):1–16.
40. Moos JH, Schrader S, Paulsen HM. Reduced tillage enhances earthworm abundance and biomass in organic farming: a meta-analysis. *Landbauforschung.* 2017;67:123–128.
41. Narayanan SP, Kurien VT, Thomas AP, Julka JM. Earthworm diversity of the Western Ghats, India: current status and future directions. *Zootaxa.* 2022;5124(4):401–435.
42. Pallas PS. Marina varia nova et rariora. *Nova Acta Acad Sci Petropolitanae.* 1877;2:229–249.
43. Reynolds JW. Earthworms utilized by the American woodcock. *Proc Woodcock Symp.* 1977;6:161–169.
44. Reynolds JW. Earthworms as bioindicators. *Soil Biol Biochem.* 1994;26(9):1319–1326.
45. Reynolds JW. Earthworm (Annelida: Oligochaeta) parasites, parasitoids and predators: a review. *Megadrilogica.* 2021;26(4):51–60.
46. Reynolds JW. Key to global megadrile families and some additional potential cohabitants (Annelida). *Megadrilogica.* 2026;29(11):191–225.

47. Rouse GW, Pleijel F. *Polychaetes.* Oxford: Oxford University Press; 2001.
48. Savigny JC. Analyses des travaux de l'Académie Royale des Sciences pendant l'année 1821. *Mem Acad Sci Inst Fr.* 1826;5:176–184.
49. Sawyer RT. *Leech biology and behaviour.* Oxford: Oxford University Press; 1986.
50. Sharma P, editor. *Research trend in environmental science.* Vol. 11. New Delhi: Akinik Publications; 2022.
51. Siddall ME, Borda E. Phylogeny and revision of the leech family Glossiphoniidae. *Am Mus Novit.* 2003;3401:1–18.
52. Singh AP, Bhatnagar A. Leech therapy in plastic and reconstructive surgery. *Indian J Plast Surg.* 2011;44(3):395–402.
53. Skoczeń S. Gromadzenie zapasów pokarmowych przez niektóre ssaki owadożerne. *Przegl Zool.* 1970;14(2):243–248.
54. Timm T. Aquatic Oligochaeta of the Soviet Union. *Hydrobiologia.* 1984;115(1):125–130.
55. Verrill AE. Report upon the invertebrate animals of Vineyard Sound and adjacent waters. *Rep US Comm Fish.* 1873;1:295–778.
56. Ude H. Über die Rückenporen der Terricolen Oligochäten. *Z Wiss Zool.* 1885;43:87–143.
57. Webster HE. The Annelida Chaetopoda of the Virginian coast. Trans Albany Inst. 1879;9:202–269.
58. Xu Q, Yang X, Song J, Ru J, Xia J, Wang S, *et al*. Nitrogen enrichment alters multiple dimensions of grassland functional stability. Ecol Lett. 2022;25(12):2713–2725.
59.