# Vermicology I. Ecological considerations of the earthworms used in vermiculture – a review of the species.

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Abstract

Of a worldwide total of almost 4,000 described megadrile earthworms, broadly divided in to "Litter", "Topsoil" or "Subsoil" species, detailed ecological studies have been made on fewer than 20 of these. Those used in vermiculture are mainly "Litter" species that include, but are not limited to: *Eisenia fetida* (Savigny, 1826) "Tiger Worm" and its sibling species *E. andrei* Bouché, 1972 "Red Tiger Worm"; *Perionyx excavatus* Perrier, 1872 "Indian Blue"; *Eudrilus eugeniae* (Kinberg, 1867) "African Nightcrawler"; *Amynthas corticis* (Kinberg, 1867) and *A. gracilis* (Kinberg, 1867) "Pheretimas"; *Eisenia hortensis* (Michaelsen, 1890) and *Eisenia (=Dendrobaena) veneta* (Rosa, 1886) "European Nightcrawlers"; and *Lampito mauritii* Kingerg, 1867 "Mauritius Worm". Additional species used in Australia include *Anisochaeta buckerfieldi* (Blakemore, 1997), *Anisochaeta* spp. and *Dichogaster* spp. Claimed use of *Lumbricus rubellus* Hoffmeister, 1843 "Red Worm" and *Polypheretima elongata* (Perrier, 1872) are probably misidentifications. Other species are used regionally for land rehabilitation and for fishing bait markets, eg. *Lumbricus terrestris* Linneaus, 1758 "Canadian Nightcrawler" which is sold at a premium in North America. This paper will consider the taxonomy, biology, and ecological requirements of vermicomposting worms, briefly discussing their reproductive capacities, regeneration potential, and species associations - including their complement of predators and parasites.

Keywords: - Eisenia fetida, Perionyx, Eudrilus, vermicomposting, vermiculture.

## Introduction

Ecological strategies of various earthworms are functions of their behaviour, morphlogy, demography, and habitat, and have been divided in categories by various authors - most notably by Lee (1959, 1985, 1987) and, independently, by Bouché (1971, 1972, 1977).

Lee proposed readily interpretable categories that are broadly applicable to several common earthworm families, these are:

1. **Litter species** – live on the soil surface, feeding in the mulch layers.

2. **Topsoil species** – burrow in the A-horizon of the soil, but feed at the surface where they produce casts.

3. **Subsoil species** – dwell entirely underground in the B and/or C horizons of the soil feeding in the lower root zones.

Bouché's equivalent categories, most applicable to European lumbricids, were:

1. **Epigeés –** living and feeding in the surface mulch layers.

2. **Anéciques –** burrow into the soil (in A to C horizons) but feed at the surface.

3. **Endogées** – live in the mineral horizons, feeding on organic matter in the soil.

Neither scheme encompasses the full repertoire of behaviours nor habitats, and several species either overlap categories or fail to comply with any, indicating the need for further categories. These two schemes are essentially similar in their parameters, differing slightly in interpretation as compared in Table 1, although Lee's terms take precedence and largely supercede the equivalent French terms.

Perel (1977) had divided lumbricids into 'humus feeders' and 'humus formers' which corresponds closely with detritivores, that feed directly on organic substrates and geophages, that feed on oganic matter incorporated in the soil. More recently, Buckerfield (1994) has simplified classification of commonly encountered earthworms as either 'composters' or 'fieldworkers'. Species used in vermiculture and vermicomposting are mostly derived from litter species and are classed as 'composters'. These species can be readily cultured in rich organic substrates but in general do not survive well in the field, and are not the same as the most beneficial of agricultural and horticultural 'fieldworker' species. Vermiculture and vermicomposting appear to be expanding industries, the success of their operation relies on the behavioural and ecological characteristics of the particular earthworms involved and, as a prerequisite, correct identification of the species is important.

This paper will consider the taxonomy, biology, and ecological requirements of vermicomposting worms, briefly discussing their reproductive capacities, regeneration potential (from Blakemore, 1998, 1999a; Gates, 1972; Sims & Gerard, 1985; Stephenson, 1930), and species associations - including their parasitic companions (eg. Rysavy, 1969).

## Materials and Methods

Details of the taxonomic characters required for classification of species are not explicitly presented here, although many will be evident from the species descriptions provided. Overviews of the features employed in oligochaete taxonomy are available from various sources, for example Stephenson (1930), Lee (1959), Sims & Gerard (1985) (for lumbricids), Gates (1972), and Easton (1979) (for pheretimoids). Conventions, abbreviations and technical and anatomical terms (with notes on their importance to systematics) are also given in these text. Only, the main species used in vermiculture will be described and other species included in the discussion. Major synonymies are given and taxonomic authorities can be resourced from references given above, and from Reynolds & Cook (1976).

## Species descriptions

### *Eisenia fetida* (Savigny, 1826).

**Fig. 1**.

*Enterion fetidum* Savigny, 1826.

*Lumbricus semifaciatus* Burmeister, 1835.

*Lumbricus annularis* Templeton, 1836.

*Lumbricus foetidus*, Dugès, 1837 (invalid emendation).

*Lumbricus olidus*, Hoffmeister, 1842.

*Lumbricus luteus* Blanchard, 1849.

*Lumbricus rubro-fasciatus* Baird, 1873.

*Allolobophora foetida*, Eisen, 1874.

*Lumbricus annulatus* Hutton, 1877.

*Endrilus? annulatus*, Smith, 1887.

*Eisenia foetida*, Michaelsen, 1900:475; Gates, 1972: 97.

*Helodrilus (Eisenia) foetidus*, Michaelsen, 1910.

*Eisenia fetida fetida* Bouché, 1972: 380.

*Eisenia fetida*; Sims and Gerard, 1985.
Other synonymies are given in Easton (1983), species name often incorrectly cited as "*E. foetida*".

Behaviour: if agitated, ejects yellow coelomic fluid with distinctive 'nutty' smell. Lengths: (27) 35-120 (130) mm. Widths: 3-6 mm. Segments: 100 (±20). Colour: variable, from light pink to deep chestnut brown dorsally, buff ventrally, iridescent, clitellum pale, intersegmental furrows often yellow giving a banded appearance, tip of tail often bright yellow from accumulation of coelomocytes. Prostomium: open epilobous. First dorsal pore: (3/4) 4/5 (5/6). Setae: 8 per segment closely paired, ventral setae of 9-12,13 and 25-32,33 often in papillae. Nephropores: inconspicuous. Clitellum: saddle-shaped, variable 26,27-32,33. Male pores: equatorial slits, almost lateral and confined to 15 in either large or only slightly raised tumescences. Female pores: minute, just lateral to b in 14. Spermathecal pores: paired 9/10 and 10/11 near dorsal line. Genital Markings: tubercula pubertatis solid ridges lateral to B lines, variable but mostly often in 28-30. Hearts: 7-11. Gizzard: in 17-18. Calciferous glands or diverticula: intramural (in 10-14). Intestine origin (caeca, typhlosole): 15, typhlosole present. Nephridia: holoic with bladders. Testis/sperm funnels: 10 and 11, seminal vesicles 9-12. Ovaries: small in 13. Prostates: none. Spermathecae: two small pairs in 9 and 10, spherical ampullae, adiverticulate. Gut contents: fine soil and organic material. Cocoons: deposited near surface, 2.4-5.2 mm long by 2.3-4.4 mm wide, darken with age; eight to twenty embryos present but only one to five hatch, usually two. Reproduction: described as 'facultatively self-fertilizing', true parthenogenesis has not been proven (Sims & Gerard, 1985). Regeneration: possible anteriorly from 23/24 and posteriorly from 20/21 (Gates, 1972).

Distribution: cosmopolitan, commonly bred in worm farms around the world and sold as "Tiger worms" or "Red wrigglers", or "Red worms" also known as the "Brandling".

Habitat: worm beds, in woodlands in wet litter, rarely found in fields and gardens (Sims & Gerard, 1985). Remarks: originally of European origin, *E. fetida* is closely similar to *Eisenia nordenskioldi* (Eisen, 1879), and is now widely distributed (see Gates, 1972). This species is sometimes classed as haemerobiont (entirely dependent on culture), however, it is also recorded from a range of habitats around the world such as taiga and steppes in Russia, under manure piles and in gardens in Sydney and under pastures in New Zealand (Lee, 1959). Gates (1972) reported that repeated attempts to introduce it to tropical lowlands are known to have failed. Variations, particularly with respect to colouration are frequently observed. An interesting finding by Miles (1963) was that when *Eisenia fetida* was cultured in sterile soil to which soil fungi and bacteria were added, specimens failed to grow, but when soil protozoa were added, the worms grew to maturity. Other data from Gates (1972) are that: specimens have survived total immersion for periods up to 6 months; maximum life expectancy has been found to be 5 years, but average life span is 503-594 days depending on temperature; food passes through the gut in 8-15 hours; in Pakistan, a population of 1,000 increased to 456,380 in about six months. Gates (1972:103) also states that despite claims, true hybrids have not been proven, and although banded forms were cross bred with unicolored French worms, these F1 hybrids were sterile. Parasites: ciliates, sporozoans, cestodes, nematodes and one dipteran are listed by Gates (1972).

### ***Eisenia andrei* Bouché, 1972.**

*Eisenia foetida* var. *unicolor* André, 1963: 24.

*Eisenia fetida andrei* Bouché, 1972: 381; Jaenike, 1982: 6.

*Eisenia unicolor* Øien & Stenersen, 1984: 277.

*Eisenia andrei*; Sims & Gerard, 1985.

Notes: *E. andrei* is a sibling species with *E. fetida* and both are morphologically undistinguished. *E. andrei* also has variable colouration – it is a 'molecular species' that can only be differentiated using electrophoresis. It is sometimes reported from either side of the Atlantic from low pH and laboratory cultures of *E. fetida*.

### ***Perionyx excavatus* Perrier, 1872.**

**Fig. 2**

*Perionyx gruenewaldi* Michaelsen, 1891.

*Perionyx sp.* Friend, 1911.

*Perionyx fulvus* Stephenson, 1918.

?*Perionyx turaensis* Stephenson, 1920; Gates, 1972.

Behaviour: moves rapidly to escape handling and exudes coelomic fluid, sometimes tail autotomy occurs. Lengths: 30-180 mm. Width: 2.5-7 mm. Segments: 115-178. Colour: anterior dorsum violet-red with blue iridescence; ventrum pale cream (spermathecae show through); clitellum ligher or darker colour. Prostomium: open epilobous, faint or slight ventral cleft on peristomium. First dorsal pore: 4/5 (or 5/6), partly occluded on clitellum. Setae: small black and numerous, 40-54, no noticeable mid-ventral gap but narrow mid-dorsal gap. Nephropores: not obvious, but possibly minute ventral pores near furrows. Clitellum: annular 13,14-17,18. Male pores: on 18 closely apposed, deep, wedge-shaped clefts in a common depressed but tumid field; no setae seen in the tumid area between the male pores but, in each cleft when held open, are seen circles of 5-6 black penial setae suggesting that they are eversible during amphimixis. Female pores: single central anterior to setal arc on 14. Spermathecal pores: two pairs on 7/8 and 8/9 or anterior margin of segments: large, open pores with intervening furrows obliterated, same width apart as male pores. Genital Markings: none. Septa: 7/8 and 8/9 have some thickening others weak, 9/10-11/12 appear to incorporate seminal vesicles. Dorsal blood vessel: single continuous on pharynx. Hearts: latero-oesophageal hearts in 9-12, commissurals anteriorly, supraoesophageal (with lateral vessels?) in 9,10-12,13. Gizzard: absent or rudimentary in 6. Calciferous glands or diverticula: in 10-12 the oesophagus is swollen and vascularised, while in 13 it is especially swollen to form lateral pouches, the internal surfaces are ridged. Intestine origin (caeca, typhlosole): 18, acaecate, atyphlosolate. Nephridia: holoic, convoluted tubules obvious in the clitellar region but smaller anteriorly; avesiculate. Testis/sperm funnels: large, iridescent testis funnels paired in 10 and 11, free or incorporated in opalescent seminal vesicle sacs of 9-12. Ovaries: in 13 as large pair of palmate to saccular glands with numerous egg strings. Prostates: large, almost spherical, racemose glands with central U-shaped duct joined entally by vasa deferentia, or conical by folding around thick duct, confined to 18. Spermathecae: in 8 and 9, two pairs with large tapering or bilobed ampullae each with various closely-attached flat or lobed iridescent diverticula; duct short and stout. Gut contents: mainly organic material. Habitat: rainforest vegetation, in piles of manure, and worm beds. Sold as “Indian Blue”, Distribution: Vietnam, Andaman Islands, India, Sri Lanka, Myanmar, Malaya, Indonesia, Borneo, Philippines, Taiwan, Hawaii, West Indies, Madagascar, Samoa, Fiji, Australia. The Type-locality is

Saigon (types in Paris Museum), although the original home is believed to be in the Himalayas. Transportation, presumably by human agency, in the last few millennia has greatly extended its range. However, as with other members of the genus, *P. excavatus* has been recorded from under bark of standing and fallen trees and in leaf axils, thus it is not improbable that drifting logs may be responsible for some oceanic transportation. Remarks: *P. excavatus* has been recorded from tropical lowlands of Myanmar to 3,000 m in the Himalayas and Gates (1972) says "no other species of earthworm is presently known to live in so many different kinds of climates", although this accolade is claimed for some lumbricids. It requires considerable moisture and organic matter to survive but breeds year-round, going into diapause during drought. Gates (1972) failed to observe amphimixis which has led some to conclude that it is parthenogentic, although no study has reared isolated specimens to confirmed this. Moreover, spermatozoal iridescence, the presence of penial setae and widely receptive spermathecal pores suggests that sexual reproduction is the norm. Regeneration: very commonly observed, possible from 17/18 anteriorly and 20/21 posteriorly. Parasites: Gates (1972) only lists the sporozoan *Monocystis longispora* Boison, 1957, and nematode, *Scolecophilus mus* Timm, 1967.

## ***Eudrilus eugeniae*** **(Kinberg, 1867).**

**Fig. 3**

*Lumbricus eugeniae* Kinberg, 1967: 98.

*Eudrilus decipiens* Perrier, 1871.

Length: 90-165 mm, posterior tapers and becomes flattened. Width: 4-8 mm. Segments: 145-203. Colour: red-brown dorsum, anterior bright blue/green iridescent, ventrum beige, clitellum dark (sometimes lighter) brown, posterior colour faded. Behaviour: active with rapid escape response, if captured become very placid and can be readily handled. Prostomium: small, open epilobous. First dorsal pore: none. Setae: 8 per segment closely paired, ab absent from 18. Nephropores: just behind anterior furrow of each segment (longitudinal slits) from 3/4 in C or slightly more median (sometimes in D). Clitellum: 14-17, interrupted ventrally. Male pores: in 17 on tips of longitudinally grooved, tapering, eversible penes in large ventral chambers retracted as lateral slits with wrinkled lips reaching 17/18, just anterior to 17/18 in line with b setae. Female pores: combined with "spermathecal pores". Spermathecal pores: pair lateral, presetal in 14 as raised ventral apertures intrasegmental and just anterior to c setae. Genital Markings: large central raised pad centred in 17 between male pores and faintly repeated in 18. Septa: from 4/5: 7/8/9 and 14/15 thickened. Dorsal blood vessel: single truncated at anterior hearts. Hearts: hearts 7-11. Gizzard: weakly muscular in 5 immediately behind pharyngeal mass. Calciferous glands or diverticula: ventral set in 10 and 11 (concealed by seminal vesicle): large and pink due to blood supply with many internal lamellae; in 13 (concealed by seminal vesicle) a pair of lobular, yellow calciferous glands which are medially placed lateral to the oesophagus and ducted posteriorly into it in 13. This latter pair supplied by largish blood vessels (from supra-oesophageal vessels). Intestine origin (caeca, typhlosole): 14. Nephridia: pair of large coiled nephridia obvious in each segment from 4. Testis/sperm funnels: testis not found, but large sacs seen in 10 and 11; seminal vesicles occupy 11 and 12 and are filled with coagulum. Ovaries: large egg filled sacs attached to each spermathecal atrium by long coiled tubes in 14. Prostates: large pair of digitiform euprostates, with white muscular sheen from 18-23; acutely muscular enlargements of loop of paired sperm ducts which attach to apex of copulatory chamber mound internally. A smaller blind duct attaches to base of mound mesially. Spermathecae: atrium with muscular sheen in 14, extends back into long flaccid, convoluted gland, filled with coagulum and enclosed sheath; at junction oviduct attaches and is opposed by small glandular outgrowth. Gut contents: soil and organic matter (this species appears to be an adaptive feeder and will survive in unamended soil in the glasshouse but also flourishes on organic material). Distribution: West African origin, peregrine or introduced into many countries in North America, India and in South America; recently confirmed from Australia (Blakemore, 1994, 1999b). Habitat: plentiful in coastal, shaded grasslands of West Africa, also found in worm beds and compost. Remarks: Brisbane specimens were from stock established from cocoons obtained from Canada. In North America, this species is especially favoured for breeding as fishing bait where it is known as the "African Nightcrawler". Despite its potential for colonization, there are as yet no feral records of it in North America (Gates, 1972) nor Australia, and such records from New Zealand are now known to be misidentifications. Attempts to establish it in natural environments found that the worms do very well until the temperature drops to 40° F, at which time they die (Gates, 1972 p 52). This species is also recommended as food for fish, birds etc. that refuse the more commonly cultured *Eisenia fetida* - it is the preferred food for duck-billed platypuses kept by the Queensland National Parks and Wildlife Service in Brisbane (G. Bosanquet, pers. comm.). This genus is bi-parental characterised by internal fertilisation and *E. eudrilidae* produces cocoons that are dark coloured and a tapered lemon-shape. This species also produces copious surface casts which are very distinctive as small pellets. Parasites are not reported by Gates (1972).

### ***Amynthas corticis*** **(Kinberg, 1867).**

*Perichaeta corticis* Kinberg, 1867: 102.

*Megascolex diffringens* Baird, 1869.

*Perichaeta peregrina* Fletcher, 1886/7.

*Perichaeta nipponica* Beddard, 1893.

*Pheretima clerica* Benham 1947.

*Pheretima campestris* Lee, 1952 (not *P. campestris*, Goto and Hatai, 1898).

*Perichaeta heterochaeta*, Michaelsen, 1891.

*Pheretima heterochaeta*, Michaelsen, 1907/9.

*Pheretima divergens yunnanensis* Stephenson, 1912.

*Pheretima mirabilis* Gates, 1934.

*Pheretima diffringens*, Gates, 1972 (*syn. divergens, heterochaeta, heteropoda, indica, nipponica, oyamai, tajarownsis, ?toriii, ?hatomajimensis*).

*Amynthas diffringens (=corticus (sic))*, Sims and Easton, 1972.

*Amynthas corticis*, Easton, 1982; Sims & Gerard, 1985: 128.

Note: name sometimes name misspelled as "corticus" . Diagnosis: *Amynthas* with paired spermathecal pores c. 1/3 body circumference apart in furrows 5/6/7/8/9; genital markings paired and variable near spermathecal pores. Lengths: (45) 120-160 (270) mm, body circular. Widths: 4-5 mm. Segments: (79) 105-118 (121). Colour: dark chocolate brown, green-iridescent dorsum; ventrum paler; clitellum yellowy buff. Behaviour: typically a vigorous lashing when exposed and rapid, snaking escape; yellow coelomic fluid ejected and possible autotomy of caudal segments. Setae: numerous: ventral series partly visible on clitellum. Spermathecal pores: four pairs in 5/6/7/8/9 0.3 circumference apart. Genital markings: various, paired presetal small disks with opaque centres, possibly some also nearer spermathecal pores, in some or all of on vi-ix (postsetal on v-viii and also near male pores?). Internally small stalked glands are associated with these markings. Intestine origin (caeca, typhlosole): in 15,16 the intestine widens appreciably (small paired supra-intestinal "lymph" glands present after 18 dorsally on gut); simple, laterally paired caeca 27-24,22, typhlosole present further posteriorly. Distribution: This species is the most widely distributed of the allochthonous species of the pheretimoid group, having been recorded from temperate and tropical regions throughout the world. Tropical records are rarer, and usually from higher altitudes. The indigenous range of the species is in east and south-east Asia. *A. corticis* has usually been reported under the name of its junior synonyms of *Pheretima diffringens* or *P. peregrina* (eg. in New Zealand) or, in earlier papers, as *P. heterochaeta*. In Australia it was believed to have been initially introduced from Mauritius in plant pots to Sydney nurseries, and it has also been recorded from Qld, NSW, WA, and Tasmania (see Blakemore, 1999b; Easton, 1982). Remarks: Active and multiplying rapidly throughout the year under favourable conditions, this worm has been reported to wander at night to infest plant beds of plant nurseries where it is sometimes problematical (in Gates, 1972). These characteristics, along with its regeneration potential, may account for the records of transportation of this worm exceeding those of the peregrine lumbricids. However it may also be restricted by low temperature tolerance and is said to be absent from Scottish greenhouses with a temperature below 15°C and is susceptible to flooding (Gates, 1972, p 177-180). Sometimes found in association with similar species (with which it may be easily confused), including *Amynthas gracilis*, and *A. rodericensis*, and *Metaphire californica* (Kinberg, 1867). Barois (1992) discusses the mutualistic microbiology of this species and of *A. gracilis*. Reproduction: parthenogenesis is implied by the reduced, parasitized or incomplete reproductive organs throughout most of its range. Regeneration: mainly of tail segments. Parasites: *Monocystis* gregarine sporozoans often infest internal organs.

### ***Amynthas gracilis* (Kinberg, 1867).**

*Nitocris gracilis* Kinberg, 1867: 112.

*Perichaeta hawayana* Rosa, 1891.

*Perichaeta bermudensis* Beddard, 1892.

*Amyntas hawayanus*, Michaelsen, 1899.
*Pheretima hawayana*, Stephenson, 1912.
*Amynthas hawayanus*, Sims and Easton, 1972.
*Amynthas gracilis*, Easton, 1982; Sims & Gerard, 1985.

Diagnosis: *Amynthas* with paired spermathecal pores, c. 1/3 of the body circumference apart in furrows 5/6/7/8; intestinal caeca simple. Genital markings near male pores.

Note: Stephenson, 1923 included quadrithecal morphs in *P. hawayana (?syn. barbadensis, pallidus*), which may actually be referrable to *Amynthas morrisi* group of Sims and Easton, 1972. Distribution: from tropical and warm temperate localities on most continents - in Sao Paulo, Brazil it is the commonest species in gardens (Gates, 1972) and the most numerous in Hawai'i (Nakamura, 1992); the original home is possibly in China. For Australia, it has been recorded from Mundubbera and around Brisbane in Qld. and from the NT (Easton, 1982). *A gracilis* has usually been reported under the name of its junior synonym *A. hawayanus* Rosa, 1891 and in North America is given common names such as "Pheretima" or "Alabama Jumper", "Georgia Jumper", etc. Remarks: This species is similar to and may easily be confused with *A. corticis*, but it has only three pairs of spermathecae, is found less frequently than *A. corticis* and, in association with other *Amynthas spp*., is stated to be geophagous by Gates (1972). Reproduction: presumably bi-parental. Regeneration: first four head segments can be replaced, tail regenerations more common. Parasites: ciliates, sporozoans, nematodes, unidentified cysticercoids and an insect (Gates, 1972).

***Eisenia hortensis* (Michaelsen, 1890)** and ***Eisenia (=Dendrobaena) veneta* (Rosa, 1886)** are lumbricids that are morphologically similar, separated on whether the body length is <50 mm or >50 mm, respectively; and on whether the pigmentation is uniform or transversely striped, respectively. Both species have been recorded from compost and sewage beds in Europe, and both species have been transported overseas. Commonly known in North America as "European Nightcrawler", *E. hortensis* is widely distributed but sporadic in India, North and South America and South Africa, it has recently been discovered in Australia (Blakemore, 1999b), while *E. veneta* has only recently been reported from California (Sims & Gerard, 1985). Neither species are known to be parthenogenic, although this is anticipated, nor to have hybrids. In the UK, some specimens obtained from wormfarmers and claimed to be "Dendrobaena" were in fact *E. fetida* (H.O. Bishop, pers. comm.)

***Lampito mauritii* Kingerg, 1867** the "Mauritius Worm" is found mainly in India and Asia in compost and manure. It has strong regenerative properties and is presumed to be bi-parental. This species will luminesce in the dark. Ismail (1997) presents information on the vermicology of this species in India while arguing against deliberate transportation of exotic species or transgenic forms in favour of endemics in order to protect regional biodiversity.

Additional species used in vermiculture in India include *Octochaetona* spp. (Ismail, 1997), while in Australia *Anisochaeta buckerfieldi* (Blakemore, 1997a), *Anisochaeta* spp., *Dichogaster* spp. and *Ocnerodrilus occidentalis* Eisen, 1878 are also used (see Blakemore, 1999, 2000). A variety of different species are used regionally for land rehabilitation and for fishing bait markets, eg. *Lumbricus terrestris* Linneaus, 1758 "Canadian Nightcrawler" which is collected from Canada and sold at a premium in North America, and "scrub worms" from Tasmania that are sold as bait in Australia. However, frequent claimed use of *Lumbricus rubellus* Hoffmeister, 1843 "Red Worm" from wormfarms and of *Polypheretima elongata* (Perrier, 1872) in India, are both probably misidentifications as neither have been confirmed (see Blakemore, 1999b; Easton, 1976). Similarly, many species have in the past been confused with *Lumbricus terrestris*, or vice versa (Blakemore, 1997b). The author is aware of only one successful intensive production of *L. terrestris* proper, by Butt (1991) in the UK.

Other worms involved in vermicomposting are of Family Enchytraeidae (enchytraeid or pot worms), microdriles (small 'aquatic' worms), free-living nematodes (roundworms), and occasionally predatory leeches - including the widespread *Trocheta subviridis* Dutrochet and Australian native *Bassianobdella bundabergii* Govedich (see Govedich, 1999), and predatory planarians (flatworms). Examples of predatory planarians from French (1985) are:

*Bipalium kewense* Moseley, 1878. Probably native to Indo-China. First described from hothouses in Kew Gardens, but said to be able to survive outdoors, widespread around the world. Length up to 350 mm

*Geoplana sanguinea* (Moseley, 1877). From Australia and New Zealand. First record in British Isles, was from Tresco in 1980. Length up to 80 mm. Feeds on earthworms.

*G.coxii* (Fletcher & Hamilton) From New Zealand. First record for British Isles was from Tresco in 1975 and probably the only other British record is from Penzance. Feeds on earthworms.

*Artioposthia triangulata* (Dendy, 1894) From New Zealand. First record from Northern Ireland in 1960s, and now in Scotland and much of England. Length up to 200 mm. Feeds on earthworms.

*Kontikia andersoni* Jones, 1981 The genus is principally Indo-Pacific, but the origin of this species is not known. First found in Northern Ireland in 1978 (but not described until 1981). It grows up to 23 mm and it has been found on Tresco and in Cornwall near Wadebridge.

*Rhyncodemus sylvaticus* (Leidy, 1851) Country of origin unknown. First found in Britain in 1960. Length up to 10 mm. Recorded in Cornwall.

*Dolichoplana striata* Moseley, 1877 From Indo-Malaya. Usually in greenhouses but in southern USA it lives outdoors and is a nuisance in in earthworm raering-beds. Grows up to 200 mm So far known only from Botanic Gardens in Glasnevin, Ireland.

*Microplana humicola* Vejdovsky Jones (1988) believes that it is native to Britain, although it was not reported until the 1980s. It is only 4 mm long and is white with a darker,greenish anterior end.

*M.terrestris* (Muller, 1774) and *M.scharffi* (von Graff, 1899) are native to Britain. Grow up to 26 mm. or 90 mm, respectively. Common to many parts of British Isles, including Cornwall. Feed on earthworms.

Other organisms have interactions with earthworms in compost processing including mammals, birds and reptiles, plus various invertebrates such as molluscs (eg. snails and slugs), isopods (woodlice/slaters), collembolans (springtails), spiders and mites, dipteran and beetle larvae, as well as particular groups of microbes, fungi and algae (Edwards & Fletcher, 1988). Some of these organisms can be potential pests whereas most are beneficial or benign. Certain earthworm species will have different symbioses with various organisms that are mutalistic, commensal, or parasitic, making the compost ecosystem a richly dynamic habitat.

Earthworms, like all other organism, have their complement of predators and parasites. Gates (1972) refers to the parasites of various species, and associations between nematodes and earthworms were reviewed by Poinar (1978) who listed some 150 species only some of which are parasitic to hosts other than earthworms. Edwards and Lofty (1977) and Rysavy (1969) summarised a range of helminth parasites for which earthworms are intermediate hosts. Earthworms are also hosts to *Histomonas* sp., a protozoan parasite causing blackhead disease in fowl. In Michigan, high infection of lumbricid cocoons with the mite species *Histoiostoma muchiei* were reported by Oliver (1962). Infection of human lungs, kidneys and mesenteries by nematodes apparently derived from earthworms are known (eg. Ghabbour, 1966). Earthworms have also been found to be carriers of foot-and-mouth disease of cattle and to distribute both pathogenic and symbiotic microbes of plants (see Lee, 1985: 153, 274; Reddell & Spain, 1991). Thus, while earthworms may have many beneficial attributes, their long evolutionary history and intimate contact with soil has resulted in various parasitic and symbiotic associations, some of which are of concern to human health and to farm quarantine. Much more caution is required when transporting vermicomposting species, and especially unsterilized bedding material, from one area to another.

Suitability and efficacy of different vermicomposting species

Several authors have compared species: Neuhauser *et al*. (1988) studied all five, Edwards (1988) four, and Edwards & Bater (1992) and Reinecke *et al*. (1992) made comparisons between the first three in the list of the following species: *Eisenia fetida*, *Eudrilus eugeniae*, *Perionyx excavatus*, *Eisenia veneta* and *Amynthas corticis*. In general, *Eisenia fetida* was found to be superior to the other species in terms of its wide temperature tolerance, high reproductive rate and efficiency in converting organic wastes. *Eudrilus eugeniae* and *Perionyx excavatus* were also effective but their narrow temperature tolerances tends to limit them to more tropical situations. The fecundity of *Eudrilus eugeniae* is lower than that of *E. fetida* but studies by Graff (1982) showed *E. eugeniae* had its highest reproduction when fed on sewage sludge. A summary of findings from these and several other reports is given in Table 2.

Optimal environmental conditions for the growth and reproduction of *Eisenia fetida* fed on aerobic wastes are a temperature range of 15-25°C, moisture content of 43-90% and pH of 5-9 (Kaplan *et al*. 1980a; Edwards, 1988; Neuhauser *et al.*, 1988; Edwards & Bater, 1992; Reinecke *et al.*, 1992). *Eudrilus eugeniae* has narrower optimum temperatures in the range 20-29°C (Neuhauser *et al.*, 1988, Neuhauser *et al.*, 1979) while for *Perionyx excavatus* temperature optima are 15-30°C (Neuhauser *et al.*, 1988). Results of a study by Reinecke *et al*. (1992) confirmed that *Eisenia fetida* had a wider tolerance for temperatures than either *E. eugeniae* or *P. excavatus*. Although temperature tolerances depend somewhat on the acclimation of earthworms, temperatures of 30°C were found to be detrimental to the growth of five species by Neuhauser *et al*. (1988) and 35°C was fatal. Nevertheless, it may be possible to utilise heat generated by the composting processes to enable heat-tolerant species to survive in cooler climates and, where there is provision for movement, earthworms will retreat from unfavourable to more conducive conditions. Little is known of the environmental requirements and vermicomposting capabilities of *Eisenia andrei* a species occasionally found with *E. fetida* in cultures (see Table 2).

In theory, maintaining a mixture of several species (a polyculture) could accomplish greater stabilization than cultures of a single species due to variable partitioning of resources and environmental tolerances. However, in experiments it was not obvious that polyculture had any advantages in vermicomposting compared to single cultures of *Eisenia fetida* or *Eudrilus eugeniae* (Neuhauser *et al*., 1988), and in mixed cultures *E. fetida* often becomes dominant (Edwards & Bater, 1992).

## Discussion and conclusion

Of a worldwide total of almost 4,000 described megadrile earthworm species, detailed ecological studies have been made on fewer than 20 of these. Approximate regional species totals of both endemic and exotic species are: UK and Ireland - 45; Japan – 78; North America – 160; NZ – 192; Tasmania – 260; India – 350; and mainland Australia – 350 spp with an estimate of total number two or three times this large (Blakemore, 1999b; Easton, 1980; Ismail, 1997; Reynolds, 1998; Sims & Gerard, 1985). After Lee (1959), three general categories are used to describe the ecological strategies of commonly encountered earthworms, the three classifications are: Litter, Topsoil, or Subsoil species. Only about six or seven species are widely used in vermicomposting, and these are mostly derived from Litter species, although *Amynthas gracilis*, *Eudrilus eugeniae*, and *Lampito mauritii* can possibly can be classified as Topsoil species. Many other species have potential and may be suitable for use on particular substrates, either alone or in polyculture; more work is required to identify and investigate these possibilities, especially amongst endemic faunas. The starting point would be to determine which native and naturalized species occur 'naturally' in sewage treatment plants, composts, and other organically rich substrates. Importation of extraneous species is often unnecessary and dangerous - Australian restrictions on earthworm importations require lengthy and expensive 'Risk Analyses' that, if approved, allow only surface sterilized cocoons from countries free of foot-and-mouth disease (Australian Quarantine and Inspection Service, pers. comm.).

While the importance of correctly identifying the species concerned is stressed, the most ubiquitous earthworm in vermicomposting is undoubtedly *Eisenia fetida*, with *Perionyx excavatus* and *Eudrilus eugeniae* also used in tropical regions. Advantages of *E. fetida* are that it has rapid growth, feeds on almost any organic matter, has a wide temperature tolerance, can be easily handled, has a high reproductive rate and has more known about its biology than any other species (Hartenstein, 1983; Edwards and Bater, 1992). Very frequently this species has been misidentified and confused with other species, and claims of "superworm" hybrids are sometimes made. Invariably these hybrids have been either *E. fetida*, or some other well-known species, according to Gates (1972: 103). Earthworm hybrids are "unknown" and Gates (1972: 117-118) questions the veracity of a report of interspecies crossing of *L. rubellus* with *L. festivus* (Savigny, 1826).

Vermicomposting earthworms can recycle and convert organic matter into vermicompost, an important soil conditioner and additive, and also produce earthworm biomass. Earthworms are high in protein so are nutritious to stock and game, moreover they are the source of enzymes and pharmaceuticals used in traditional and technological medicines (Stephenson, 1930; Gates; 1972; Lee, 1985; Ishmail, 1997; Whiston & Seal, 1988). Earthworms may have many beneficial attributes, their long evolutionary history and intimate contact with soil has resulted in various symbiotic, mutualistic and parasitic associations, some of which are of concern to human health and farm quarantine. Some caution is required when transporting vermicomposting species, and especially unsterilized bedding material, from one area to another due to attendant liability of spreading predators, parasites and disease.

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**Table 1. Ecological characteristics of earthworms after schemes of Lee/Bouché.**

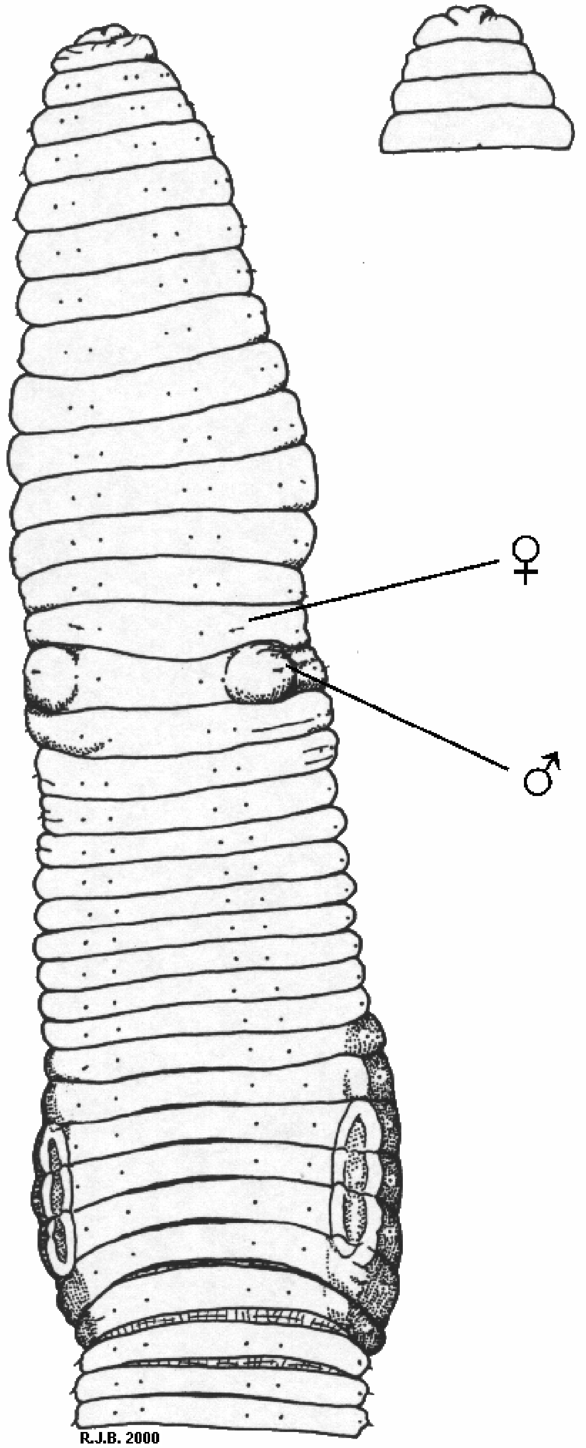
| Character | Litter spp/epigees | Topsoil spp/aneciques | Topsoil spp/endogees |
|---|---|---|---|
| Food | Meso/Meso | Macro/Macro | Micro/Micro |
| Predation | High/High | Medium/Medium | Low/Low |
| Mobility | High/High | Medium/Medium | Low/Low |
| Size | Small/Small | Medium/Large | Large/Medium |
| Pigment | Strong/Strong | Medium/Medium | Weak/Weak |
| Longevity | Low/Low | Medium/High | High/Medium |
| Generation time | Low/Low | Medium/Medium | High/Medium |

**Table 2. Comparison of vermicomposting earthworm species.**

Note, most recent nomenclatural changes give these names: *Amynthas diffringens* = *Amynthas corticis; Amynthas hawayana* = *Amynthas gracilis; Eisenia foetida* = *Eisenia fetida; Dendrobaena veneta* = *Eisenia veneta.*

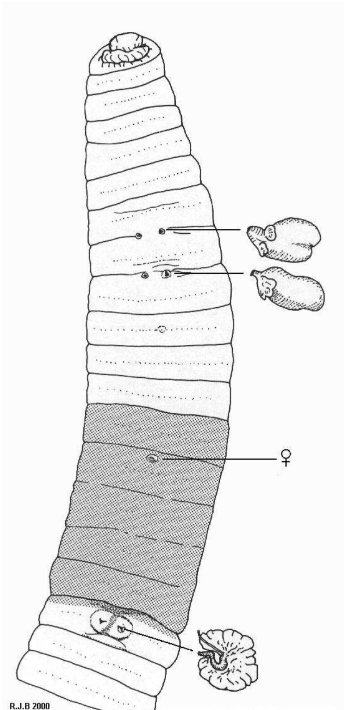
| Species (common name) | Temperature ranges | Usefulness | References |
|---|---|---|---|
| Amynthas gracilis | 20-28°C optimum | Not suitable | Kaplan et al. (1980b); Neuhauser et al. (1988) |
| Amynthas rodericensis | 20-28°C optimum | Not suitable | Kaplan et al. (1980b) |
| Eisenia andrei (Red tiger worm)* | Unknown | Characteristics presumed similar to *E. fetida* but is less common (low pH?) | Haimi & Huhta (1978); Sheppard (1988); van Gestel et al. (1992) |
| Eisenia fetida (Tiger worm)* | 0-35°C tolerated; 20-25°C optimum | Effective and most widely used; high reproductive rate; wide tolerances | Watanabe & Tsukamoto (1976); Tsukamoto & Watanabe (1977); Kaplan et al. (1980a); Graff (1982); Hartenstein (1983); Reinecke & Venter, 1985; Venter & Reinecke, 1987; Neuhauser et al. (1988); Edwards, 1988; Edwards & Bater, 1992. |
| Eisenia veneta | 3-33°C tolerated; 15-25°C optimum | Efficient at converting sludge but has a low reproductive rate | Neuhauser et al. (1988); Edwards & Bater, 1992. |
| Eudrilus eugeniae (African night-crawler) | 9-30°C restriction; 20-28°C optimum | Effective, but has narrow temperature requirements. | Neuhauser et al. (1979); Graff (1982); Neuhauser et al. (1988); Edwards, 1988; Edwards & Bater, 1992. |
| Lumbricus rubellus (Red worm?)* | 13-22°C optimum | Dubious - not well researched | Pincince et al. (1981)* |
| Perionyx excavatus (Indian blue worm) | 9-30°C restriction; 15-30°C optimum | Prolific and effective but has restricted temperature range; tolerates low pH | Kale et al. (1982); Neuhauser et al. (1988); Edwards, 1988; Edwards & Bater, 1992; Reinecke & Reinecke, 1994. |

* *Eisenia andrei*, *E. fetida* and *Lumbricus rubellus* may have been confused in earlier literature and are all called "Red worms" by some worm growers.

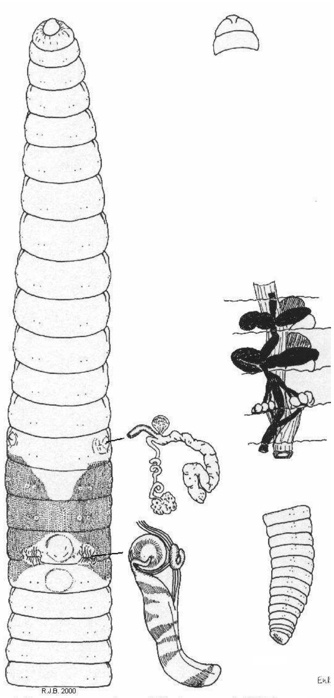



Eisenia fetida (Savigny, 1826)

1




*Perionyx excavatus*




Eudrilus eugeniae (Kinberg, 1867)

Figure legends [better quality electronic images will be supplied for publication]:

**Fig. 1** *Eisenia fetida* from Brisbane worm farm (a) ventral view (b) prostomium.

**Fig. 2** *Perionyx excavatus* (a) ventral view, (b) prostate with vas deferens joining duct, (c) spermathecae.

**Fig. 3** *Eudrilus eugeniae*, (a) ventral view, (b) vasa deferentia unite to form the euprostates leading to the copulatory chamber, (c) spermathecal aperture and combined ovary (oviduct unravelled), (d) prostomium, (e) calciferous glands and (f) dorso-lateral view of pygomere.