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Segmented worms (Phylum Annelida): a celebration of twenty years of progress through *Zootaxa* and call for action on the taxonomic work that remains

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Abstract

Zootaxa has been the leading journal on invertebrate systematics especially within Annelida. Our current estimates indicate annelids include approximately 20,200 valid species of polychaetes, oligochaetes, leeches, sipunculans and echiurans. We include herein the impact of *Zootaxa* on the description of new annelid species in the last two decades. Since 2001, there have been over 1,300 new annelid taxa published in about 630 papers. The majority of these are polychaetes (921 new species and 40 new genera) followed by oligochaetes (308 new species and 10 new genera) and leeches (21 new species). The numerous papers dealing with new polychaete species have provided us a clear picture on which polychaete families have had the most taxonomic effort and which authors and countries have been the most prolific of descriptions of new taxa. An estimated additional 10,000+ species remain to be described in the phylum, thus we urge annelid workers to continue their efforts and aid in training a new generation of taxonomists focused on this ecologically important group.

Key words: biodiversity, polychaetes, oligochaetes, leeches, sipunculans, echiurans

Introduction

Among the superphyletic grouping Lophotrochozoa (= Spiralia), the Annelida is one of the most speciose phyla (third largest behind the Mollusca and Platyhelminthes). Presently, the Annelida (including Clitellata, Echiura, Pogonophora, Sipuncula and others as discussed below) has over 20,180 described species (Fig. 1), but it is projected to contain 30,000 or more species (Larsen *et al.* 2017; Pamungkas *et al.* 2019; Capa & Hutchings 2021).

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The evolutionary relationships of annelids among lophotrochozoans remains incompletely resolved, with evidence placing them variably as sister to other phyla that possess trochophore larvae (Dunn *et al.* 2014; Kocot *et al.* 2017; Bleidorn 2019; Laumer *et al.* 2019; Capa & Hutchings 2021).

Within the Annelida, recent phylogenetic analyses based on molecular (e.g., Weigert & Bleidorn 2016; see reviews in Struck 2019 and Capa & Hutchings 2021) and morphological (e.g., Bartolomaeus *et al.* 2005; Purschke *et al.* 2014) data indicate a basal grade of worms is found in the phylum and includes the Palaeoannelida (Oweniidae + Magelonidae), Amphinomida, Chaetopteridae, and Sipuncula. The basal position of Oweniidae and Magelonidae is also supported by central nervous system features (Beckers *et al.* 2019a; b). The earliest polychaete fossil dates to Cambrian (~514 MYA) and suggests ancestral crown annelids exhibited some features similar to magelonids (Chen *et al.* 2020) including possession of parapodia. The oldest fossil annelid is a sipunculan (~520 MYA) and there remains debate about the morphology and lifestyle of the ancestral annelid (see Weigert *et al.* 2014; Nanglu & Caron 2018; Han *et al.* 2019; Parry *et al.* 2019).

Although sipunculans are one of the smallest lineages (~162 species) within the Annelida, they have been in the spotlight since the early 2000s when discussions of their placement within annelid radiation were reinvigorated by phylogenetic and phylogenomic studies (Boore & Staton 2002; Teldford *et al.* 2005; Dunn *et al.* 2008; Mwinnyi *et al.* 2009; Struck *et al.* 2011; Weigert *et al.* 2014; 2016). Significant revisions within sipunculan classification have been made over the past ~ 140 years (Selenka *et al.* 1883; Fisher 1952; Stephen 1965; Stephen & Edmonds 1972; Cutler 1994), but only after inclusion of molecular sequences, morphological data, and/or a combination of the two (Maxmen *et al.* 2003; Staton 2003, Schulze *et al.* 2005, 2007; Kawauchi *et al.* 2012; Lemer *et al.* 2015) was a strongly supported monophyly of Sipuncula was recovered. Based on six genes regions, Kawauchi *et al.* (2012) established a current classification of sipunculans, recognizing 16 genera organized into six well-supported monophyletic families, confirmed later by phylogenomic analysis of RNA sequence data (Lemer *et al.* 2015).

The remainder of the annelids include a large radiation termed Pleistoannelida consisting of two large monophyletic groups: Errantia (~5,909 species) and Sedentaria (~13,641 total species among the sedentariate polychaetes and Clitellata) (Fig. 1), with an additional ~50 species of questionable affinity and considered *incertae sedis* (Pamungkas *et al.* 2019; Struck 2019). The Errantia (including the Myzostomida) is composed of at least 49 families of aciculate polychaetes, with the most abundant families being Syllidae, Polynoidae, and Nereididae. The sedentariate polychaetes (including the Echiura) is a paraphyletic group composed of at least 43 families, with the most abundant families being Sabellidae, Spionidae, Terebellidae, and Serpulidae (Fig. 1).

The Sedentaria also includes groups historically thought to be distinct from annelids (e.g., Echiura, Siboglinidae (Pogonophora + Vestimentifera) and the derived Clitellata (Oligochaeta + Hirudinea). The oligochaetes (~7,585 species among 35 families; DriloBASE 2021; WoRMS Editorial Board 2021) are paraphyletic without Hirudinea (~916 species among 20 families including Hirudinida, Branchiobdellida and Acanthobdellida) (Sket & Trontelj 2008; Phillips *et al.* 2019; Tessler *et al.* 2018; Williams & Weaver 2019; Erséus *et al.* 2020). Based on fossil cocoons and earthworm burrows, clitellates are represented in the fossil record from the Middle Triassic (Parry *et al.* 2019). In contrast to the clitellates—which are mostly freshwater or terrestrial, lack such parapodia, and exhibit direct development—the polychaetes are largely marine, possess parapodia and head appendages, and produce trochophore larvae; of course, there are many exceptions to these "rules" within both groups. By our estimate, the Annelida includes approximately 20,188 valid species; the current totals of species in all annelid families are shown in Fig. 1.

Most of the diversity within the Annelida is among groups traditionally considered members of the class Polychaeta (see Pamungkas *et al.* 2019). Although not a monophyletic grouping, the polychaeta is still a useful designation indicating predominately marine worms that typically possess parapodia and a larval phase, which are lacking in clitellates (Glasby *et al.* 2021). Thus, Zootaxa has "polychaeta" editors, the World Register of Marine Species still recognizes the "Class" status of the group (Read & Fauchald 2021), and there remains an active International Polychaetology Association, members of which have described much of the diversity within the annelids since its formation in 1986 (Blake 2011). Knowledge of the diversity within the polychaetes continues to grow with groups such as the Myzostomida (entirely parasitic on or in echinoderms, Struck 2019; Weigert & Bleidorn 2016) being placed as members of the Errantia (Helm *et al.* 2012; Summers & Rouse 2014; Weigert *et al.* 2014). More recently an additional parasitic group, the Orthonectida (endoparasites of a range of invertebrate hosts, including annelids) are suspected to be highly derived annelids, lacking nearly all diagnostic morphological characters for the group (Schiffer *et al.* 2018; Bondarenko *et al.* 2019; Zverkov *et al.* 2019). Both myzostomids and orthonectids have been difficult to place due to long branch-attraction artifacts in phylogenetic reconstruction based on molecular data (Struck 2019; Zverkov *et al.* 2019).

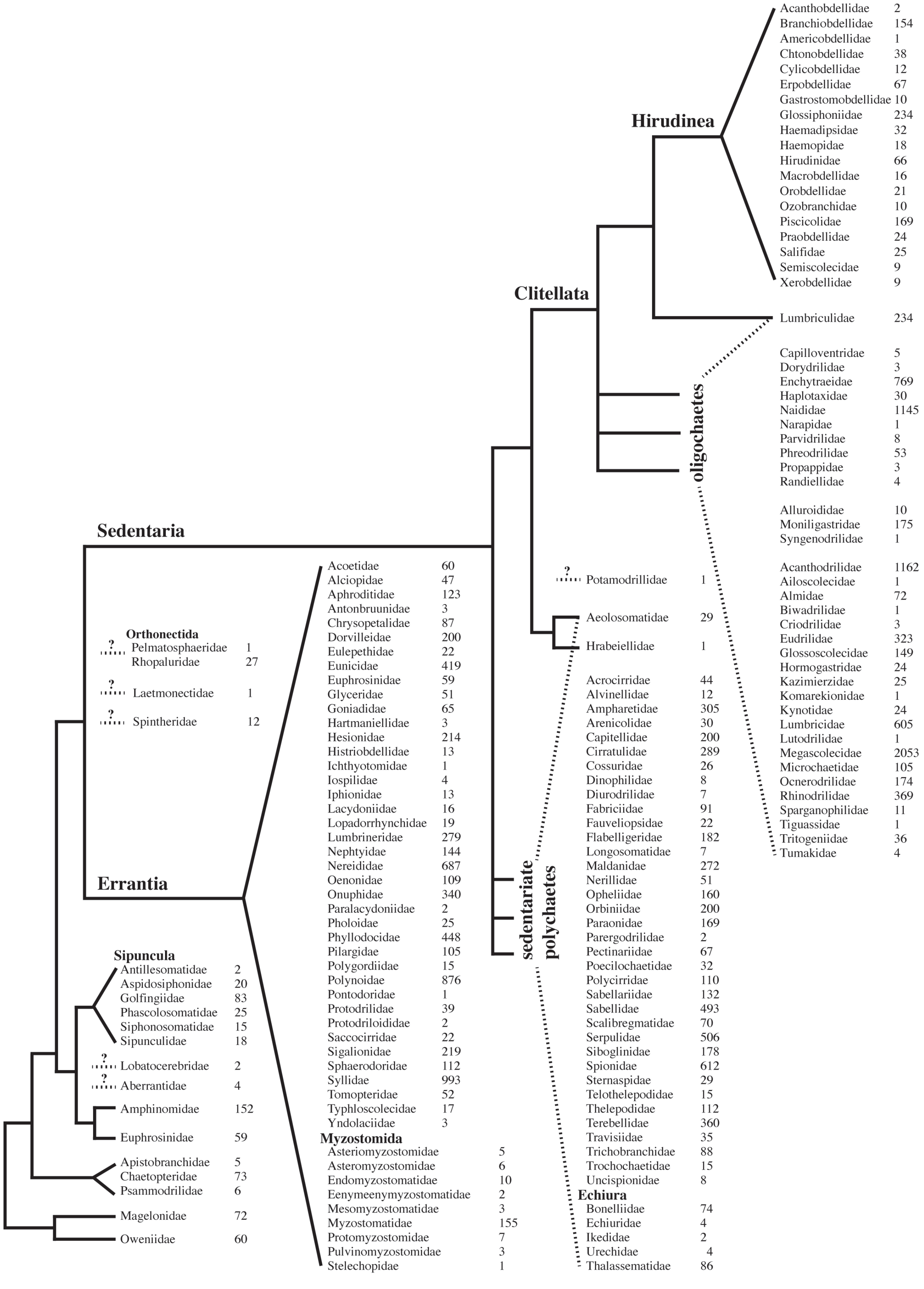
Hirudinea
Acanthobdellidae 2
Branchiobdellidae 154
Americobdellidae 1
Chtonobdellidae 38
Cylicobdellidae 12
Erpobdellidae 67
Gastrostomobdellidae 10
Glossiphoniidae 234
Haemadipsidae 32
Haemopidae 18
Hirudinidae 66
Macrobdellidae 16
Orobdellidae 21
Ozobranchidae 10
Piscicolidae 169
Praobdellidae 24
Salifidae 25
Semiscolecidae 9
Xerobdellidae 9
Clitellata
Lumbriculidae 234
oligochaetes
Capilloventridae 5
Dorydrilidae 3
Enchytraeidae 769
Haplotaxidae 30
Naididae 1145
Narapidae 1
Parvidrilidae 8
Phreodrilidae 53
Propappidae 3
Randiellidae 4
Alluroididae 10
Moniligastridae 175
Syngenodrilidae 1
Acanthodrilidae 1162
Ailoscolecidae 1
Almidae 72
Biwadrilidae 1
Criodrilidae 3
Eudrilidae 323
Glossoscolecidae 149
Hormogastridae 24
Kazimierzidae 25
Komarekionidae 1
Kynotidae 24
Lumbricidae 605
Lutodrilidae 1
Megascolecidae 2053
Microchaetidae 105
Ocnerodrilidae 174
Rhinodrilidae 369
Sparganophilidae 11
Tiguassidae 1
Tritogeniidae 36
Tumakidae 4
Sedentaria
?
Potamodrillidae 1
Aeolosomatidae 29
Hrabeiellidae 1
sedentariate polychaetes
Acrocirridae 44
Alvinellidae 12
Ampharetidae 305
Arenicolidae 30
Capitellidae 200
Cirratulidae 289
Cossuridae 26
Dinophilidae 8
Diurodrilidae 7
Fabriciidae 91
Fauveliopsidae 22
Flabelligeridae 182
Longosomatidae 7
Maldanidae 272
Nerillidae 51
Opheliidae 160
Orbiniidae 200
Paraonidae 169
Parergodrilidae 2
Pectinariidae 67
Poecilochaetidae 32
Polycirridae 110
Sabellariidae 132
Sabellidae 493
Scalibregmatidae 70
Serpulidae 506
Siboglinidae 178
Spionidae 612
Sternaspidae 29
Telothelepodidae 15
Thelepodidae 112
Terebellidae 360
Travisiidae 35
Trichobranchidae 88
Trochochaetidae 15
Uncispionidae 8
Echiura
Bonelliidae 74
Echiuridae 4
Ikedidae 2
Urechidae 4
Thalassematidae 86
Errantia
Acoetidae 60
Alciopidae 47
Aphroditidae 123
Antonbruunidae 3
Chrysopetalidae 87
Dorvilleidae 200
Eulepethidae 22
Eunicidae 419
Euphrosinidae 59
Glyceridae 51
Goniadidae 65
Hartmaniellidae 3
Hesionidae 214
Histriobdellidae 13
Ichthyotomidae 1
Iospilidae 4
Iphionidae 13
Lacydoniidae 16
Lopadorrhynchidae 19
Lumbrineridae 279
Nephtyidae 144
Nereididae 687
Oenonidae 109
Onuphidae 340
Paralacydoniidae 2
Pholoidae 25
Phyllodocidae 448
Pilargidae 105
Polygordiidae 15
Polynoidae 876
Pontodoridae 1
Protodrilidae 39
Protodriloididae 2
Saccocirridae 22
Sigalionidae 219
Sphaerodoridae 112
Syllidae 993
Tomopteridae 52
Typhloscolecidae 17
Yndolaciidae 3
Myzostomida
Asteriomyzostomidae 5
Asteromyzostomidae 6
Endomyzostomatidae 10
Eenymeenymyzostomatidae 2
Mesomyzostomatidae 3
Myzostomatidae 155
Protomyzostomidae 7
Pulvinomyzostomidae 3
Stelechopidae 1
Orthonectida
?
Pelmatosphaeridae 1
Rhopaluridae 27
?
Laetmonectidae 1
?
Spintheridae 12
Sipuncula
Antillesomatidae 2
Aspidosiphonidae 20
Golfingiidae 83
Phascolosomatidae 25
Siphonosomatidae 15
Sipunculidae 18
?
Lobatocerebridae 2
?
Aberrantidae 4
Amphinomidae 152
Euphrosinidae 59
Apistobranchidae 5
Chaetopteridae 73
Psammodrilidae 6
Magelonidae 72
Oweniidae 60

FIGURE 1. Schematic representation of main branchings in the phylogeny of the Annelida, showing relationships of major subgroups. Traditional Polychaeta are all Annelida minus Clitellata, and traditional Oligochaeta are all Clitellata minus Hirudinea. Families per higher-level sub-taxon are listed in alphabetical order. In "oligochaetes" the upper group represents basal taxa, mostly aquatic, the lower group represents the Crassiclitellata (true earthworms); the middle group (3 families) includes earthworm-like worms; together with Crassiclitellata it forms the Metagynophora Jamieson, 1988. Acanthodrilidae here include Benhamiidae and Octochaetidae. Phylogeny based on Weigert & Bleidorn (2016), Struck (2019) and Erséus et al. (2020), for further phylogenetic resolution of families see these references. Taxa noted with vertical text and with dashed lines indicate paraphyletic groups (sedentariate polychaetes, oligochaetes). Taxa denoted with a dashed line and question mark are considered Annelida *incertae sedis* and are currently debated in terms of their phylogenetic position (see discussion in Struck et al. 2019; Capa & Hutchings 2021); some additional aberrant taxa (Lophotrochozoa *incertae sedis*) are not included. Data on numbers of species primarily derived from Pamungkas et al. (2019), Read & Fauchald (2021), WoRMS Editorial Board (2021), Handbook of Zoology, Annelida (Purschke et al. 2019a, b; 2021) and DriloBASE (2021).

Within Hirudinea, major changes in the classification of the group have been proposed since the inclusion of molecular data, together with the implementation of robust phylogenetic methods. Now, it is broadly recognized that Hirudinida (true leeches), Acanthobdellida (bristle worms, parasitic on boreal salmonid and thymallid fishes) and Branchiobdellida (primarily on freshwater crayfish, but also reported from blue crabs (*Callinectes* sp.), cave isopods, and freshwater crabs and shrimp), all parasitic, predatory or commensal species, form a monophyletic group nested within Oligochaeta (Apakupakul *et al.* 1999; Martin 2001; Tessler *et al.* 2018), named Hirudinea in Erséus *et al.* (2020). Rhynchobdellida (proboscis-bearing leeches), once considered one of the two largest orders of leeches, was found to be paraphyletic, after which the erection of two new groups was proposed (Apakupakul *et al.* 1999; Tessler *et al.* 2018). Some of the historically recognized leech families were found to be either para- or polyphyletic, such as Hirudinidae, in which the European medicinal leech *Hirudo medicinalis* is included, resulting in the recognition of at least three separate families (Phillips & Siddall 2009; Phillips *et al.* 2010).

The conceptual and methodological revolution linked to cladistic analysis and, above all, the access, via DNA, to a new class of characters have radically changed the classification of the Clitellata over the last 20 years (summarized in Martin 2015). Recently, phylogenomic analyses have produced a consistent and strongly supported phylogeny of the clitellate annelids (Erséus *et al.* 2020). A major contribution of these studies has been to change the commonly held view of many authors that the family Haplotaxidae occupied a basal position within the oligochaetous Clitellata, in close proximity to the "hypothetical" ancestor and close to the ancestor of the megadriles (Crassiclitellata), an assumption based mainly on anatomical simplicity and assumed plesiomorphic characters of the reproductive system (Brinkhurst 1991; Erséus 2005). Further, while some argued in favour of an aquatic origin for oligochaetes (Omodeo 1998; Timm 1981), in line with the traditional views (e.g., Stephenson 1930; Michaelsen 1928-1934), others maintained that the first clitellates were terrestrial (e.g., Purschke 2003). Today, it is clear that the aquatic families Randiellidae, Parvidrilidae and Capilloventridae are at the base of Clitellata, suggesting an aquatic, possibly freshwater species as most recent common ancestor of the clitellates, while the Haplotaxidae and Crassiclitellata appear deeply nested in the phylogenetic tree of the clitellates (Erséus *et al.* 2020).

In the aquatic oligochaetes, major changes in classification in the last years include the fusion of the two species-rich families Naididae and Tubificidae into one family after recognizing that the former was polyphyletic and the latter paraphyletic (Envall *et al.* 2006); this "mega"-family, into which later the species-poor Opistocystidae were fused as well (Erséus *et al.* 2010), received the name Naididae for reasons of nomenclature (Erséus *et al.* 2008). However, some systematists maintain Tubificidae in their traditional circumscription (Timm & Martin 2015), and classificatory problems remain in Rhyacodrilinae, the paraphyletic stem group of all the other subfamilies in the Naididae (Sjölin *et al.* 2005).

In Crassiclitellata, a taxon that includes most of the earthworms (Jamieson 1988), the number of families has increased by the split of Glossoscolecidae into Rhinodrilidae (James 2012) and Glossoscolecidae s.s. (James 2012; James & Davidson 2012), and by the placement of some genera of Microchaetidae in families of their own, Tritogeniidae (Plisko 2013) and Kazimierzidae (Nxele *et al.* 2016), while the megadiverse superfamily Megascolecoidea is not yet fully resolved at the family level. Enhanced methods integrating morphology and DNA-data have greatly expanded taxonomic knowledge in many branches and at all levels of the phylogenetic tree.

Steps have been taken to resolve problematic species groups (e.g., Chang *et al.* 2008; Szederjesi *et al.* 2018; 2019) and to achieve consistent definitions and circumscriptions of genera (e.g., Csuzdi *et al.* 2017). Molecular data confirm the correlation of clade formation and plate tectonics (e.g., Anderson *et al.* 2017), discovered almost 100 years ago (Michaelsen 1922). At lower taxonomic levels, patterns of geographic distance often reflect phylogenetic relationships better than morphological differences (e.g., Novo *et al.* 2011; Jiménez-Pinadero *et al.* 2021).

Cryptic species are common in Annelida, see the review of Nygren (2014) for polychaetes and Martinsson & Erséus (2021) for clitellates. The number of species detected below the umbrella of one morphologically defined nominal species varies between two and 16, but rarely exceeds three. It is usually in the common and widespread species where cryptic species are detected; in oligochaetes almost all common species investigated so far are species groups. It needs to be determined whether this pattern also extends to rare species or to those with a narrow distribution range. Cryptic species are increasingly being recognized with a formal description and a binomen – in the past, they often had received only informal letters or numbers. This new practice, due in part to the rapidly declining cost of molecular sequencing, will lead to more accurate estimates of diversity in these groups.

Clearly, the past 20 years has greatly expanded our knowledge of the divergent body plans and species richness in the ecologically important phylum Annelida. The purpose of this paper is to review the impact of *Zootaxa* on the field, highlighting the taxonomic and systematic accomplishments of the authors who have contributed to this journal.

Material and Methods

Data on Annelida diversity was obtained from different databases and recent publications. WoRMS Editorial Board (2021) has been the most reliable database for sipunculans, myzostomids, echiurans, polychaetes and aquatic oligochaetes ("microdriles"). A recent compilation on polychaete diversity was provided by Pamungkas *et al.* (2019) and we have updated it using the several Handbook of Zoology chapters written by polychaete specialists that contained counts of species per family (Purschke *et al.* 2019a, b; 2021).

The number of species of the terrestrial microdrile family Enchytraeidae was updated by Rüdiger Schmelz. In order to estimate the number of "earthworm" species, loosely termed "megadriles" (Brinkhurst 1982; Stephenson 1930) and comprising the taxa Crassiclitellata (Jamieson 1988) and Moniligastrida (Michaelsen 1900), the database DriloBASE (taxo.drilobase.org) was consulted. The number of species and families within Hirudinea was updated by Alejandro Oceguera-Figueroa based on recent publications.

There is a general consensus among researchers that WoRMS (WoRMS Editorial Board 2021) and DriloBASE (DriloBASE 2021) are reliable and updated sources of Annelida taxonomic data. The information contained in these databases has been added and updated with new taxonomic information as quickly as possible given the efforts of many taxonomic editors who generally are the experts on the taxonomic groups for which they are responsible.

In order to understand the impact of *Zootaxa* on the yearly description of new annelid taxa, raw data on the new polychaete taxa described from 2001 to 2020 was extracted from WoRMS (WoRMS Editorial Board 2021). In addition to the usual taxonomic information, the spreadsheet contained year, journal, and title of publication. New columns were added for gender and country of origin of the first author of the publication. Total counts of new oligochaete taxa described from 2001 to 2020 were obtained from Nomenclatura Oligochaetologica (Reynolds & Wetzel 2021) although the available annual accounting is not complete. Hirudinea data was retrieved directly from the original publications.

Results and Discussion

Importance of *Zootaxa* for the taxonomy of Annelida

Zootaxa was established in 2001 and annelid papers were initially handled by the chief editor Zhi-Qiang Zhang; since then, 17 editors have worked within the Annelida section (Table 1). Currently, there are ten editors who deal with papers on polychaetes and clitellates (leeches and oligochaetes) (Table 1). Since 2001, there have been over 1,300 new annelid taxa published in about 630 papers (see Tables 2 and 3). Three papers dealing with 23 new myzostomid species have also been published (Rouse & Grygier 2005; Summers *et al.* 2014; Kolbasova & Mekhova 2019) and handled by annelid editors. Sipunculans and echiurans are still in two separate sections of *Zootaxa* with a combined 13 papers published.

TABLE 1. Current and past Annelida editors at *Zootaxa*.

Annelida Editors	Taxa Handled
Bartz, Marie*	Oligochaeta
Dahlgren, Thomas	Polychaeta
Gordon, Dennis P.	Echiura
Hutchings, Pat*	Polychaeta
Jamieson, B.G.M.	Oligochaeta
Kawauchi, Gisele Yukimi*	Sipuncula
Maciolek, Nancy J.	Polychaeta
Magalhães, Wagner F.*	Polychaeta
Marchán, Daniel Fernández*	Oligochaeta
Nguyen, Anh D.*	Oligochaeta
Nygren, Arne	Polychaeta
Oceguera-Figueroa, Alejandro*	Hirudinea
Read, Geoffrey	Polychaeta
Rouse, Greg	Polychaeta
Schmelz, Rüdiger M.*	Oligochaeta
Sket, Boris	Clitellata
Wiklund, Helena*	Polychaeta
Williams, Jason*	Polychaeta

*denotes current editors

In the past 20 years, *Zootaxa* has been responsible for 37.5% of the new polychaete taxa with 921 new species and 40 new genera described. The percentage of *Zootaxa's* contribution has varied across the years but increased in the last decade, with authors in *Zootaxa* generally contributing half the number of yearly-described polychaetes (Table 2 and Fig. 2B).

TABLE 2. Total polychaete taxa described (genera and species) from the period of 20 years (2001–2020) including those described in *Zootaxa* and information about number of papers and pages. Data compiled and extracted from WORMs.

	Total polychaete taxa described in all journals	Total polychaete taxa described in *Zootaxa*	Number of polychaete papers in *Zootaxa*	Number of pages of *Zootaxa* polychaete papers
2001	110	0	0	0
2002	89	0	0	0
2003	124	2 (1.6%)	1	7
2004	103	12 (11.65%)	2	326
2005	100	11 (11%)	5	123
2006	130	31 (23.8%)	13	338
2007	84	30 (35.71%)	11	204
2008	73	19 (26%)	9	298
2009	186	29 (15.6%)	13	361
2010	64	30 (46.9%)	15	410
2011	111	31 (27.9%)	16	357
2012	113	62 (54.9%)	31	664

...Continued on the next page

TABLE 2. (Continued)

	Total polychaete taxa described in all journals	Total polychaete taxa described in *Zootaxa*	Number of polychaete papers in *Zootaxa*	Number of pages of *Zootaxa* polychaete papers
2013	129	53 (41.2%)	18	336
2014	87	44 (50.6%)	19	469
2015	209	146 (69.9%)	52	1440
2016	105	67 (63.8%)	22	424
2017	180	93 (51.7%)	35	868
2018	180	103 (57.2%)	27	767
2019	187	85 (45.4%)	22	578
2020	197	113 (57.4%)	28	736
Total	**2561**	**961 (37.5%)**	**339**	**8706**

Among sipunculans, ten papers were published in *Zootaxa*, and only one included a description of a new taxon (Saiz *et al.* 2015). Five papers addressed exclusively species inventories (Adrianov & Mariova 2010; Cutler *et al.* 2004; Dean *et al.* 2007; Dean *et al.* 2010; Pan-Wen & Chia-Ming 2009), and four approached distribution and ecology of a list of sipunculans from a specific area from the globe (Açik *et al.* 2005; Açik 2008; 2009; Ferrero-Vicente *et al.* 2013). The small number of species descriptions published in *Zootaxa* is not exclusive. After *Zootaxa* was established, there were in total 12 additional species added to the diversity of Sipuncula, two at the Proceedings of Biological Society of Washington (Kawauchi & Rice 2009), nine at the Phuket Marine Biological Center special publication (Hylleberg 2013), one new subspecies at *Zootaxa* (Saiz *et al.* 2015), and one reinstatement of a species previously synonymized at the Revista de Biología Tropical (Silva-Morales *et al.* 2019). It is known that this group of marine invertebrates is poorly understood, and the lower rates of sipunculans' new species descriptions reflect the absence of specialists capable of identifying and describing them. Schulze & Kawauchi (2021) summarized the state of knowledge of the number of species in Sipuncula and reinforced the detection of many lineages in different papers with molecular tools that likely represent new species or species synonymized in the past that have to be reinstated. However, they also warn that this gap may stay hidden due to the small number of specialists worldwide and the lack of investment and recognition for taxonomic work.

A total of 21 new leech species were described in *Zootaxa*, 14 of them included in Glossiphoniidae, four in Erpobdellidae, two in Orobdellidae and a new species and genus of Haemadipsidae (Table 3). Since 2001, a total of 137 new species of leeches have been described, 21 of them published in *Zootaxa*, representing 15%. *Zootaxa* is the leading journal for the publication of new leech species, followed by the American Museum Novitates (12), the Journal of Parasitology (11) and ZooKeys (11). The rest of the descriptions (82) were published in 40 different journals.

TABLE 3. Total clitellate taxa described (genera, species and subspecies) in *Zootaxa* from 2001–2020.

	Oligochaete taxa described in *Zootaxa*	Number of oligochaete papers	Leech taxa described in *Zootaxa*	Number of leech papers
2001	0	0	0	0
2002	1	1	0	0
2003	0	0	0	0
2004	14	2	0	0
2005	3	3	1	1
2006	5	6	2	3
2007	13	2	0	1
2008	7	4	0	0

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TABLE 3. (Continued)

	Oligochaete taxa described in *Zootaxa*	Number of oligochaete papers	Leech taxa described in *Zootaxa*	Number of leech papers
2009	13	6	2	2
2010	11	6	1	1
2011	12	7	3	3
2012	28	19	0	1
2013	20	9	2	2
2014	28	7	2	2
2015	24	11	1	1
2016	19	12	2	3
2017	19	9	1	2
2018	77	45	3	1
2019	8	7	1	5
2020	16	8	0	0
Total	**318**	**164**	**21**	**28**

The oligochaete papers are more numerous and include descriptions of 10 new genera and 308 new species (Table 3). Most of these species are within the families Megascolecidae (97 spp.), Enchytraeidae (53 spp.), and Glossoscolecidae (34 spp.). *Zootaxa's* contribution to yearly-described oligochaete taxa has varied throughout the years when compared to the total taxa described per year in all journals (Fig. 2A). Two special volumes edited by R. Schmelz on global diversity of earthworms and other oligochaetes (Schmelz 2012; 2018) greatly contributed to the knowledge on taxonomy, systematics and distribution of the group. The collection of oligochaete papers published in 2018 includes 40 papers and 71 new species representing a clear peak in *Zootaxa's* annual contribution to oligochaete discovery (Fig. 2A).

The Annelida section of *Zootaxa* invites manuscripts on annelid systematics, especially those dealing with few to many new taxa. Manuscripts dealing with single-species descriptions have been rejected by the polychaete editors with few exceptions that include valuable ecological, anatomical, or molecular data, phylogenetic analysis, or even descriptions of additional poorly known taxa. *Zootaxa* has also published detailed studies of morphology of particular families (Nogueira *et al.* 2010) as well as regional checklists of polychaetes. Annotated checklists on earthworms have been published for several countries, *e.g.* India (Tiwari *et al.* 2020), Serbia (Stojanovic *et al.* 2018), Greece (Szederjesi *et al.* 2017), and Vietnam (Nguyen *et al.* 2016). An annotated checklist of leeches from Iran has also been published in *Zootaxa* (Darabi-Darestani *et al.* 2016). These usually include literature revision, updated taxonomic status, distributional range, and number of endemic species.

Although *Zootaxa* has ranked 186 out of 402 journals in the category Animal Science and Zoology of Scopus (based on CiteScore 2019 counts of citations received in 2016–2019), it has been the leading journal for invertebrate taxonomy and consistently contained most of the new polychaete species descriptions (see Table 2). New species of polychaetes have been published in 147 journals in the last two decades. The contribution of specific journals to the total percentage of polychaetes described have changed considerably from the early 2000's and shifted to the predominance of a few taxonomic journals in recent years. In total, *Zootaxa* has been predominant with 961 polychaete taxa followed by the Journal of the Marine Biological Association of the U.K. (164), Zookeys (110), Records of the Australian Museum (93), Journal of Natural History (83), and Zoological Journal of the Linnean Society (72).

Some open access journals (e.g., ZooKeys and PLOS ONE) have increased their contribution to polychaete species discovery but submissions from students and researchers from developing countries are limited due to the high processing page fees. These researchers have generally preferred *Zootaxa* to publish their new taxa discoveries and this explains the low number of annelid papers published as open access (18%; 116 out of 630 papers). *Zootaxa* publishes monographs with no page limit and large contributions such as Nygren (2004: 314 pages), Blake (2017: 145 pages), and Molina-Acevedo (2018: 125 pages) would not be accepted for publication in any other no-page-fee taxonomy-based journal. The editors are usually highly involved in the editing of these large monographs and a substantial number of papers are received from non-native English speakers necessitating that all editors spend a substantial amount of time improving the language. The special *Zootaxa* volume 4019 was published as a monograph on polychaetes and allies from Lizard Island (Great Barrier Reef) that included 91 new species in 24 open-access articles and a total of 801 pages (Hutchings & Kupriyanova 2015).

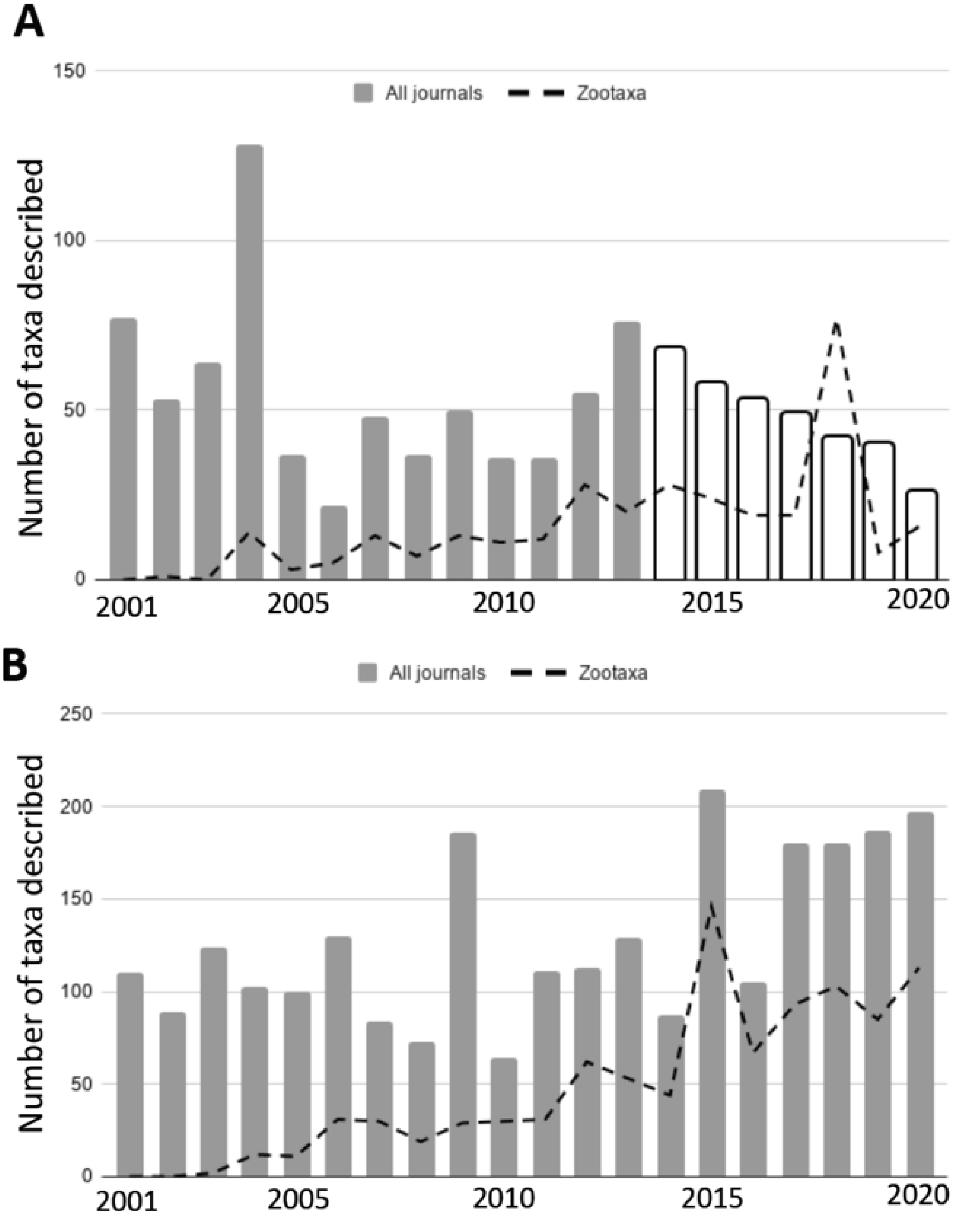

FIGURE 2. A, Total oligochaete taxa described (genera, species and subspecies) from 2001–2020 including those described in *Zootaxa*. Data retrieved from the compilation made by Reynolds & Wetzel (2021). Numbers of oligochaete taxa described from all journals from 2014–2020 are not complete and represented by white bars. B, Total number of polychaete taxa (genera and species) described in the last twenty years in all journals and specifically in *Zootaxa*.

Zoosymposia is a sister journal to *Zootaxa* designed to cover volumes of collected papers outside the scope of the latter. *Zoosymposia* volumes 2 (Maciolek & Blake 2009) and 19 (Rouse *et al.* 2020) include the proceedings of the 9th and 13th International Polychaete Conferences, respectively. *Zoosymposia* volume 2 contributed descriptions of 24 new species, which corresponded to 12% of the polychaetes described in 2009 (Maciolek & Blake 2009).

The most recent *Zoosymposia* volume (No. 19: Rouse *et al.* 2020) includes two new genera and four new species of polychaetes. Volumes 9 and 17 of *Zoosymposia* included the proceedings of the 12th and 14th International Symposium on Aquatic Oligochaeta [ISAO] (Pinder *et al.* 2014; Ohtaka *et al.* 2020). A list of citations for the published proceedings of all 14 International Symposia on Aquatic Oligochaetes (1979–2018) is presented in Wetzel (2020); many papers in which new oligochaete and branchiobdellidan taxa are described are included in these proceedings. Unlike the taxonomic scope of *Zootaxa*, the ISAO proceedings published in *Zoosymposia* present papers covering more diverse aspects of annelid biology (e.g., phylogeny, community ecology, environmental studies, biogeography, morphology, in addition to taxonomy and systematics).

Break down of number of polychaete species described in Zootaxa by family

Cirratulidae (109 species), Terebellidae *sensu lato* (100), Syllidae (91), and Spionidae (71) are the polychaete families with the largest number of new species described in *Zootaxa* and these have mostly been described in the last decade (Table 4). Syllids, terebellids, and spionids are among the most species-rich polychaete families together with polynoids and nereidids (Pamungkas *et al.* 2019) and even more species are being discovered and described. Cirratulids currently comprise about 300 described species (278 in a review by Blake & Magalhães 2019) and more than a third of these have been described in *Zootaxa*, mainly in the several monographs published by Blake (e.g., Blake 2015; 2016; 2018; 2019).

TABLE 4. Number and percentage of polychaete species and genera described in Zootaxa in the last two decades organized by families.

Family	Species	Genera	% 1st decade (2001-2010)	% 2nd decade (2011-2020)
Ampharetidae	29	2	17.2	82.8
Antonbruunidae	1	0	0.0	100.0
Capitellidae	11	0	0.0	100.0
Chaetopteridae	2	0	50.0	50.0
Chrysopetalidae	10	0	0.0	100.0
Cirratulidae	109	2	7.3	92.7
Dorvilleidae	14	0	78.6	21.4
Eulepethidae	4	0	50.0	50.0
Eunicidae	36	2	5.6	94.4
Fabriciidae	1	0	100.0	0.0
Fauveliopsidae	7	1	0.0	100.0
Flabelligeridae	44	6	0.0	100.0
Glyceridae	1	0	0.0	100.0
Hesionidae	5	0	0.0	100.0
Histriobdelldae	0	1	0.0	0.0
Lacydoniidae	1	0	0.0	100.0
Lumbrineridae	16	6	62.5	37.5
Magelonidae	6	0	0.0	100.0
Maldanidae	4	0	75.0	25.0
Nepthtyidae	7	0	14.3	85.7
Nereididae	30	0	10.0	90.0
Oenonidae	5	0	0.0	100.0
Onuphidae	33	0	9.1	90.9
Opheliidae	23	0	30.4	69.6
Orbiniidae	42	0	0.0	100.0

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TABLE 4. (Continued)

Family	Species	Genera	% 1st decade (2001-2010)	% 2nd decade (2011-2020)
Oweniidae	3	0	0.0	100.0
Paraonidae	11	0	0.0	100.0
Parergodrilidae	2	0	0.0	100.0
Pectinariidae	10	0	0.0	100.0
Pholoidae	2	0	0.0	100.0
Phyllodocidae	8	0	0.0	100.0
Pilargidae	7	0	42.9	57.1
Poecilochaetidae	2	0	100.0	0.0
Polynoidae	18	2	16.7	83.3
Sabellariidae	15	0	6.7	93.3
Sabellidae	34	4	52.9	47.1
Scalibregmatidae	8	0	50.0	50.0
Serpulidae	18	3	22.2	77.8
Siboglinidae	16	0	0.0	100.0
Sigalionidae	5	0	0.0	100.0
Sphaerodoridae	10	0	30.0	70.0
Spionidae	71	1	22.5	77.5
Sternaspidae	13	0	0.0	100.0
Syllidae	91	6	25.0	75.0
Terebellidae s.l.	100	3	27.7	72.3
Trichobranchidae	31	0	6.5	93.5
Uncispionidae	5	1	0.0	100.0
Total	**921**	**40**		

Prolific taxonomic work on Terebellidae *s.l.* has occurred in the last few decades (Hutchings *et al.* 2021) and several contributions by Hutchings, Nogueira, and Carrerette on the terebelliforms from Brazil and Australia were published in *Zootaxa* (e.g., Carrerette & Nogueira 2013; Hutchings *et al.* 2015; Nogueira *et al.* 2015a, b). Some syllid *Zootaxa* contributions include Nygren (2004) on Autolytinae with five new genera and five new species and more recently Maciolek (2020) with descriptions of 16 new species of *Anguillosyllis* Day, 1963 from deep-water sediments. The spionid genus *Prionospio* Malmgren, 1867 had 30 new species described solely in *Zootaxa* since 2009 (e.g., Dagli & Çinar 2009; Paterson *et al.* 2016; Peixoto & Paiva 2020). Other contributions, especially relevant to the description of new genera, are the several monographs revising Flabelligeridae by Salazar-Vallejo (2011; 2012a, b; 2014) in which six new genera were proposed and Carrera-Parra (2006a, b) with six new genera and ten new species of Lumbrineridae.

The annelid editors have required the citation of original descriptions whenever a name is mentioned but this practice is discouraged in some journals that publish new taxa. The reasons for the generally small number of citations of taxonomic papers have been discussed recently (see Pinto *et al.* 2021). Taxonomic annelid papers with the higher number of citations in Google Scholar Citations include a taxonomic and morphological revision of the polychaete family Serpulidae (ten Hove & Kupriyanova 2009: cited by 165), an identification guide to European terrestrial and freshwater Enchytraeidae (Schmelz & Collado 2010: cited by 154), the synonymization of the family Tubificidae with the family Naididae (Erséus *et al.* 2008: cited by 133), a taxonomic revision of one species-rich genus of Enchytraeidae (Schmelz 2003: cited by 103), a checklist of oligochaetes from Taiwan (Tsai *et al.* 2009: cited by 87), and descriptions of new species of dorvilleid polychaetes associated with dead whales (Wiklund *et al.* 2009: cited by 70).

Contribution of authors and reviewers to polychaete discovery

Zootaxa polychaete papers have been authored by taxonomists from 27 countries (Fig. 3). Countries of lead authors with the most contribution to species descriptions are USA (186 taxa), Brazil (178), Mexico (137), Australia (81 species), Spain (80), and China (69). This may be the result of more polychaetologists employed in the museums or universities of those countries. In Brazil, there are at least 39 PhD's trained to do research on polychaete taxonomy and biology (Lana *et al.* 2017), whereas in Mexico there are 11 active researchers (Salazar-Vallejo, pers. comm.) and in Australia there are currently three polychaete taxonomists employed in three museums, and three retired but are still active researchers.

Each of the current polychaete editors has handled between 4–15 manuscripts per year with an average rejection rate of 14.5%, including those manuscripts rejected for scope. While the rejection rate seems low, many papers go backwards and forward as the English is corrected and improved.

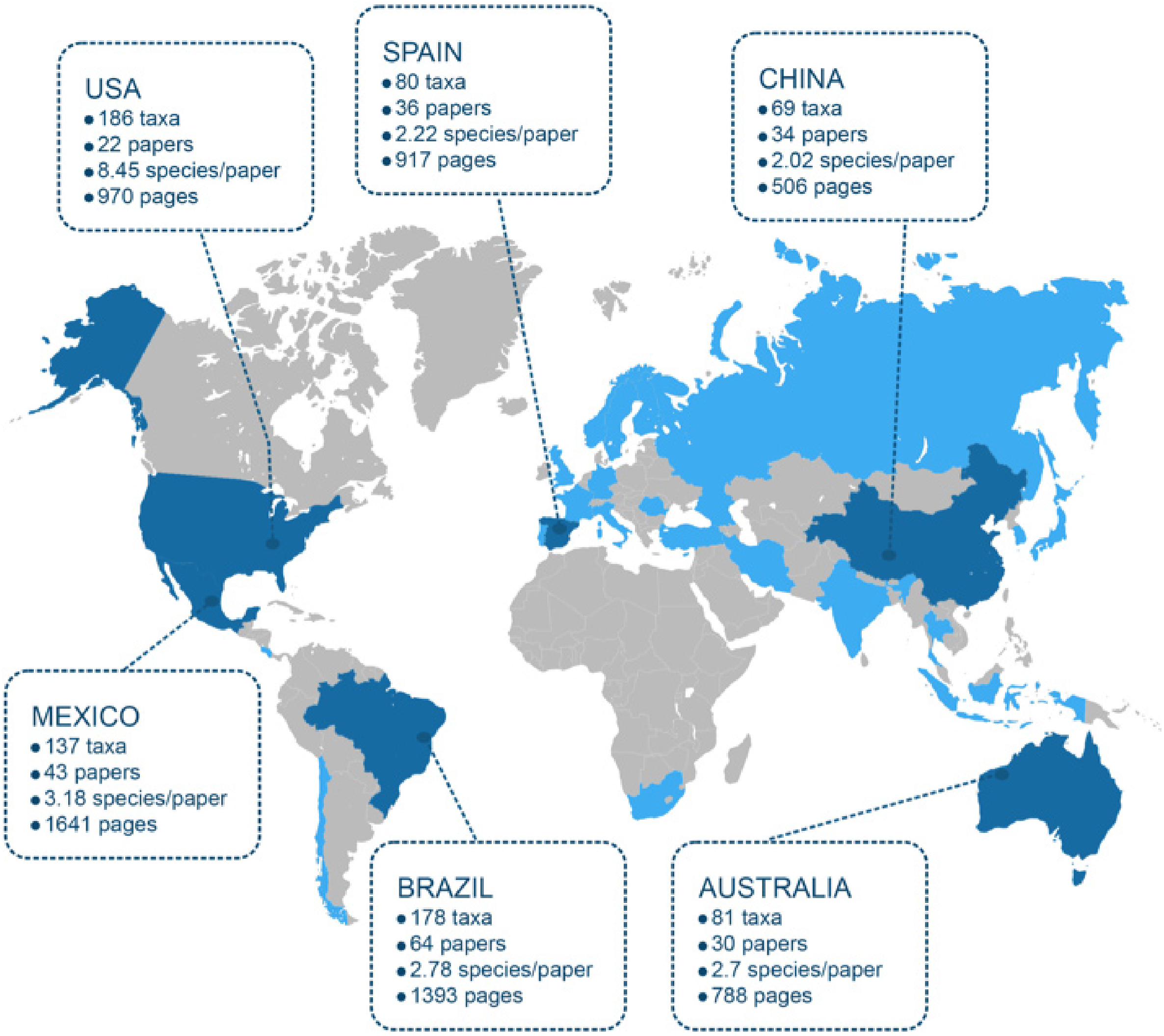

FIGURE 3. World map showing countries with the greatest number of polychaete species descriptions highlighting in light blue all the countries with *Zootaxa* contributions and in dark blue the six countries with the most number of species described in *Zootaxa*.

Female lead authors make up 31.8% of the new polychaete species descriptions in *Zootaxa* whereas male authors were the lead of 68.2% of the newly described polychaetes. Gender disparity in taxonomy has also been reported for land plant species (Lindon *et al.* 2015). Several female authors have paved the way for current polychaete taxonomists most noticeably Dr. G. Hartmann-Schröder (517 polychaete species described) and Dr. Olga Hartman

(473 species) who remain the two most prolific authors in polychaete taxonomy (Pamungkas *et al.* 2019). The most prolific authors (Table 5) in terms of new species descriptions in *Zootaxa* are also the leading authors in polychaete discovery overall (Read & Fauchald 2021; stats). Blake, Hutchings and San Martín have also been listed in Pamungkas *et al.* (2019) in their list of the 25 most prolific authors since 1850.

TABLE 5. Most prolific female and male authors to polychaete species descriptions in *Zootaxa* (2001–2020).

	Most prolific female authors		**Most prolific male authors**	
	Name	**Number of taxa described**	**Name**	**Number of taxa described**
1	Pat Hutchings	140	James A. Blake	166
2	Hannelore Paxton	33	João M. M. Nogueira	86
3	Maria Capa	29	Sergio Salazar-Vallejo	58
4	Nancy Maciolek	29	Orlemir Carrerette	56
5	Julie Bailey-Brock	28	Guillermo San Martín	48
6	Elena Kupriyanova	26	Wagner F. Magalhães	33
7	Myriam Schüller	25	Pan-wen Hsueh	32
8	María Ana Tovar-Hernandéz	24	Julio Parapar	31
9	Alexandra E. Rizzo	23	Harlan K. Dean	28
10	M. Teresa Aguado	18	Juan Moreira	26

In addition to the many issues that plague the peer-review process across all of the sciences (see review in Nguyen *et al.* 2015), *Zootaxa* is particularly vulnerable to reviewer fatigue because: 1) the contributions can often be of great length (e.g., monographs that may be several times longer than submissions to other journals), and 2) the low number of experts in some taxa can lead to repeated dependence on the same reviewers. A good example is that among the four current polychaete editors, we have had help from a total pool of 181 reviewers and the top three reviewers have given their time and efforts to revise 25, 24, and 19 manuscripts, respectively.

Thus, potential solutions to avoid reviewer fatigue include incentivizing the review process by providing compensation for reviewers and editors. Other incentives for reviewers could include free subscriptions to the journal (or items from the publisher), reduction of costs for open-access publication of reviewer's next submission in the journal, establishment of "Best Reviewer Awards" by the publisher, and including graduate students or early career researchers in the pool of reviewers (Nguyen *et al.* 2015). Currently, subject editors at *Zootaxa* are provided a discount or waiver of one paper per year for open access and this could be offered to reviewers who have repeatedly helped editors, or at least provide such reviewers a significant discount on open access fees. Of course, the problems of peer review in *Zootaxa* (and related journals) is emblematic of the main impediment in taxonomy as a whole: *limited funds for the work*. The expectation that taxonomists continue to provide their services for free (from peer review to acting as consultants on projects) is increasingly problematic considering the dearth of jobs and lack of funding (see reviews in Evenhuis 2007; Saunders 2020; Vinarski 2020; Wheeler 2020) despite many undescribed species waiting to be studied. We strongly urge for more support of editors and reviewers, especially for early career scientists who are essential for the growth of the field or even maintaining any expertise in certain taxa (Britz *et al.* 2020).

Conclusion

Great progress has been made in the past two decades; however, with perhaps only ⅔ or less of the projected total number of annelids described, much work remains. In particular, polychaete groups such as Cirratulidae, Paraonidae and Spionidae and practically all families of oligochaetes (except the monospecific ones) likely hold a wealth of undescribed diversity. We suggest training a new generation of taxonomists that use an integrative approach (Daglio & Dawson 2019), combining morphological and molecular tools to investigate new species and more accurately define species boundaries. Although many have lamented the lack of funding and job prospects for taxonomists (e.g., Saunders 2020), training in the group has the potential to be widely applicable across a range of fields. Annelids are ecologically critical in food webs and are often dominant members of benthic marine and terrestrial communities (Philipps *et al.* 2019), some are economically important (e.g., as fish bait and aquarium fish food: Read 2019), medically important (e.g., development of anticoagulants: Kvist *et al.* 2020), and useful as model systems (e.g., regeneration studies: Kostyuchenko & Kozin 2020) and as bioindicator species (Capa & Hutchings 2021). Considering earthworms, Darwin's dictum (1891: 313) still holds true: "It may be doubted whether there are many other animals which played so important a part in the history of the world, as have these lowly organized creatures." We hope to have inspired more work on Lamarck's Annélides and look forward to the new discoveries on the diversity and natural history of the segmented worms in the decades to come.

Acknowledgments

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