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Diversity of *Xiphinema americanum*-group Species and Hierarchical Cluster Analysis of Morphometrics[1]

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Abstract: Of the 39 species composing the *Xiphinema americanum* group, 14 were described originally from North America and two others have been reported from this region. Many species are very similar morphologically and can be distinguished only by a difficult comparison of various combinations of some morphometric characters. Study of morphometrics of 49 populations, including the type populations of the 39 species attributed to this group, by principal component analysis and hierarchical cluster analysis placed the populations into five subgroups, proposed here as the *X. brevicolle* subgroup (seven species), the *X. americanum* subgroup (17 species), the *X. taylori* subgroup (two species), the *X. pachtaicum* subgroup (eight species), and the *X. lambertii* subgroup (five species).

Key words: hierarchical cluster analysis, morphometrics, principal component analysis, systematics, taxonomy, *Xiphinema*.

The validity of several species attributed to the *Xiphinema americanum* group (13) has been questioned, and taxonomic identification of members of this group is sometimes difficult and uncertain.

Of the 39 species in the *X. americanum* group, 14 were initially described from North America (Table 1). With the exceptions of reports of *X. californicum* in Brazil (23) and Chile (22), *X. floridae* in Peru (18) and Chile (22), *X. georgianum* in Brazil (7), and *X. intermedium* in Pakistan (21), none of these 14 species has been reported from outside this region.

Xiphinema parvum was described from Jamaica and *X. brevicolle* and *X. peruvianum* from South America. These seem restricted to their area of origin. Because of the recent revision of the taxonomy of *Xiphinema* spp. (15), the many reports of *X. brevicolle* from other parts of the world need to be confirmed, including some reports from the United States (28), for which measurements were never provided with the identification.

Seven *X. americanum*-group species (Table 1) were originally described from Europe. Among these, *X. rivesi* has a wide distribution in North America but has been encountered only infrequently in Europe (5,35), and *X. taylori* is widespread in Central and Eastern Europe (15). The others have restricted geographical distribution, with several described from only the type locality.

Of the six species described from Africa (Table 1) only *X. diffusum* is widespread; it has been reported from Florida, South and East Africa, the Middle East, and Southeast Asia (12,15).

Nine *X. americanum*-group species were described from Asia (Table 1): six from India and one from Uzbekistan (*X. pachtaicum*), Japan (*X. incognitum*), and Thailand (*X. sheri*). Originally described from Central Asia, *X. pachtaicum* is the most common species in the Mediterranean region (12). *Xiphinema inaequale* has been reported in Peru (18) and Chile (22) and *X. ophisthohysterum* in Portugal (33).

Principal component analysis (PCA) and hierarchical cluster analysis (HCA) of morphometric measurements of 24 populations previously identified either as *X. brevicolle* or *X. diffusum* revealed the presence of four distinct phenotypes (15), which were assumed to represent four different species. We believed that similar analyses could reveal differences among the *X. americanum*-group species, thereby characterizing subgroups with common features for an easier identification at the specific level.

MATERIALS AND METHODS

Principal component analysis was performed with the published morphometric

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TABLE 1. Geographic regions of occurrence of species of the *Xiphinema americanum* group.

Geographic region of first record	Species	Notes
North America	*X. americanum*	
	X. bricolense	
	X. californicum	Also in South America (22,23)
	X. citricolum	
	X. floridae	Also in South America (18,22)
	X. georgianum	Also in South America (7)
	X. intermedium	Also widespread in Pakistan (21)
	X. laevistriatum	
	X. occiduum	
	X. pacificum	
	X. parvum	In Jamaica
	X. tarjanense	
	X. tenuicutis	
	X. thornei	
	X. utahense	
South America	*X. brevicolle*†	
	X. peruvianum	
Europe	*X. fortuitum*	
	X. incertum	In Croatia (2)
	X. madeirense	
	X. pachydermum	
	X. paramonovi	
	X. rivesi	Also widespread in North America (5,35)
	X. simile	
	X. taylori	Widespread in Italy and Central Eastern Europe (15)
Africa	*X. diffusum*	Florida, South and East Africa, Middle East, Southeast Asia (12,15)
	X. luci	
	X. oxycaudatum	
	X. pseudoguirani	
	X. silvaticum	
Asia	*X. inaequale*	Also in South America (18,22)
	X. incognitum	
	X. kosaigudensis	
	X. lambertii	
	X. neoamericanum	
	X. neoelongatum	
	X. opisthohysterum	Possibly in Europe (33)
	X. pachtaicum	Worldwide distribution, most common species in the Mediterranean (12)
	X. sheri	

† Identifications of North American populations are considered doubtful, based on a study of *X. brevicolle–X. diffusum* relationships (15).

values of 49 populations, including the type populations of the 39 species placed by Lamberti and Carone in the *X. americanum* group (13), as well as a recently described species from the island of Madeira (3). Table 2 lists geographic origins of the populations and literature references to their respective morphometric measurements, which are contained in Table 3. Variables utilized in PCA were the mean values of lengths of body, odontostyle and odontophore, the ratios a, b, c, and V, and the resulting correlation matrix.

Input variables for HCA consisted of the resulting principal components, and the average linkage method was used (31). Multivariate statistics were obtained with the program SAS, release 6.03.

TABLE 2. Populations of the *Xiphinema americanum* group selected for principal component analysis (PCA).

Species	Authority	PCA symbol	Geographic origin	Literature citation
X. americanum	Cobb, 1913	AM	Arlington cemetery, VA, USA	16
X. americanum		AM(B)	Beltsville, MD, USA	16
X. brevicolle	Lordello & Da Costa, 1961	BR	Topotypes, Brazil	15
X. brevicolle		BR(C)	Campinas, Brazil	15
X. brevicolle		BR(V)	Viçosa, Brazil	15
X. bricolense	Ebsary, Vrain & Graham, 1989	BC	Type pop., B.C., Canada	6
X. californicum	Lamberti & Bleve-Zacheo, 1979	CA	Type pop., CA, USA	12
X. californicum		CA(ME)	Mexico	12
X. citricolum	Lamberti & Bleve-Zacheo, 1979	CT	Type pop., FL, USA	12
X. diffusum	Lamberti & Bleve-Zacheo, 1979	DI	Type pop., Reunion, Africa	12
X. diffusum		DI(SA)	South Africa	15
X. floridae	Lamberti & Bleve-Zacheo, 1979	FL	Type pop., FL, USA	12
X. floridae		FL(MI)	Merrit, FL, USA	12
X. fortuitum	Roca, Lamberti & Agostinelli, 1987	FO	Type pop., Italy	29
X. georgianum	Lamberti & Bleve-Zacheo, 1979	GE	Type pop., GA, USA	12
X. inaequale	(Khan & Ahmad, 1975) Khan & Ahmad, 1977	IN	Holotype, India	10
X. incertum	Lamberti, Choleva & Agostinelli, 1983	IC	Type pop., Bulgaria	14
X. incognitum	Lamberti & Bleve-Zacheo, 1979	IG	Type pop., Japan	12
X. intermedium	Lamberti & Bleve-Zacheo, 1979	IT	Type pop., FL, USA	12
X. kosaigudensis	Quraishi & Das, 1984	KO	Type pop., India	27
X. laevistriatum	Lamberti & Bleve-Zacheo, 1979	LV	Type pop., FL, USA	12
X. lambertii	Bajaj & Jairajpuri, 1977	LA	Type pop., India	1
X. luci	Lamberti & Bleve-Zacheo, 1979	LC	Type pop., Senegal	12
X. madeirense	Brown, Faria, Lamberti, Halbrendt, Agostinelli & Jones, 1992	MD	Type pop., Madeira	3
X. neoamericanum	Saxena, Chhabra & Joshi, 1973	NA	Type pop., India	32
X. neoelongatum	Bajaj & Jairapuri, 1977	NE	Type pop., India	1
X. occiduum	Ebsary, Potter & Allen, 1984	OC	Type pop., Sask., Canada	5
X. opisthohysterum	Siddiqi, 1961	OP	Paratypes, India	12
X. oxycaudatum	Lamberti & Bleve-Zacheo, 1979	OY	Type pop., Nigeria	12
X. pachtaicum	(Tulaganov, 1938) Kirjanova, 1951	PT	Polignano, Italy	19
X. pachydermum	Sturhan, 1983	PC	Type pop., Portugal	33
X. pacificum	Ebsary, Vrain & Graham, 1989	PF	Type pop., B.C., Canada	6
X. pacificum		PF(PV)	Pacific Vineyards, B.C., Canada	6
X. paramonovi	Romanenko, 1981	PA	Type pop., Russia	30
X. parvum	Lamberti, Ciancio, Agostinelli & Coiro, 1991	PV	Type pop., Jamaica	15
X. peruvianum	Lamberti & Bleve-Zacheo, 1979	PE	Type pop., Peru	12
X. pseudoguirani	Lamberti, Ciancio, Agostinelli & Coiro, 1991	PS	Type pop., Madagascar	15
X. rivesi	Dalmasso, 1969	RV	Type pop., France	4
X. sheri	Lamberti & Bleve-Zacheo, 1979	SH	Type pop., Thailand	12
X. sheri		SH(P)	Pakchong, Thailand	12
X. silvaticum	Luc & Williams, 1978	SL	Type pop., Mauritius	26
X. simile	Lamberti, Choleva & Agostinelli, 1983	SM	Type pop., Bulgaria	14
X. tarjanense	Lamberti & Bleve-Zacheo, 1979	TA	Type pop., FL, USA	12
X. taylori	Lamberti, Ciancio, Agostinelli & Coiro, 1991	TY	Type pop., Italy	15
X. tenuicutis	Lamberti & Bleve-Zacheo, 1979	TN	Type pop., TN, USA	12
X. thornei	Lamberti & Golden, 1986	TH	Type pop., CO, USA	17
X. thornei		TH(GC)	Griley, CO, USA	17
X. thornei		TH(MI)	ID, USA	17
X. utahense	Lamberti & Bleve-Zacheo, 1979	UT	Type pop., UT, USA	12

TABLE 3. Average morphometric values† of the populations used for principal component analysis of the *Xiphinema americanum* group.

Population‡	L	A	B	C	CIP	V	ODS	OPH	ORAP	TAIL	J	DLIP	DGR	DBOES	DV	DA	DBJ
AM	1.50	54.0	5.80	49.0	1.80	50.0	69.0	44.0	53.0	31.0	5.0	8.0	19.0	26.0	28.0	17.0	5.00
AM(B)	1.70	50.0	7.00	48.0	1.80	51.0	73.0	47.0	63.0	36.0	9.0	10.0	24.0	30.0	35.0	20.0	8.50
BC	1.90	56.0	7.50	57.0	1.50	52.0	87.0	51.0	68.0	36.0	6.5	—	—	—	—	25.0	9.00
BR	2.10	44.5	6.40	77.8	1.00	53.0	101.9	57.0	86.3	26.8	8.0	11.5	29.8	39.4	46.6	26.6	13.70
BR(C)	1.90	44.9	6.10	73.7	0.90	50.5	89.9	53.0	79.6	25.3	7.7	12.4	30.6	37.1	41.5	26.6	14.00
BR(V)	2.10	47.9	6.20	86.9	0.90	52.3	104.5	58.6	90.0	24.3	7.9	11.6	30.8	38.1	44.0	26.8	14.40
CA	2.00	60.0	6.80	63.0	1.60	51.0	90.0	48.0	76.0	31.0	6.0	10.0	23.0	29.0	33.0	19.0	7.00
CA(ME)	1.90	56.0	6.90	58.0	1.70	51.0	86.0	48.0	74.0	33.0	8.5	10.5	25.0	31.0	34.0	20.0	9.00
CT	1.70	45.5	6.00	49.0	1.60	52.5	86.0	47.0	66.5	35.0	13.0	12.5	31.5	36.5	38.5	22.0	8.75
DI	1.70	47.0	6.90	72.0	0.90	50.0	87.0	50.0	62.0	24.0	12.0	11.0	26.0	33.0	36.0	25.0	17.00
DI(SA)	1.90	44.8	6.40	79.5	0.90	50.7	88.4	53.2	72.4	23.3	11.4	12.7	29.9	37.2	41.2	26.9	18.70
FL	1.80	44.0	6.30	59.0	1.30	51.0	90.0	54.0	74.0	31.0	9.0	13.0	29.0	36.0	42.0	25.0	9.00
FL(MI)	1.70	43.0	6.00	63.0	1.10	51.0	87.0	52.0	74.0	27.0	7.0	13.0	30.0	36.0	40.0	24.0	9.00
FO	2.60	83.4	7.10	75.7	1.90	54.0	102.0	50.6	83.2	35.3	8.9	8.7	21.8	27.5	32.1	18.6	8.30
GE	1.90	47.0	6.10	64.0	1.30	53.0	112.0	53.0	98.0	31.0	12.0	12.0	32.0	38.0	41.0	23.0	10.00
IC	1.90	57.0	6.40	69.0	1.50	57.0	92.0	51.0	71.0	28.0	7.0	9.0	22.0	29.0	34.0	19.0	10.00
IG	1.90	45.0	6.30	62.0	1.10	51.0	87.0	52.0	72.0	30.0	10.0	12.0	28.0	37.0	42.0	28.0	15.00
IN	1.78	43.4	5.20	68.4	—	52.0	104.0	60.0	—	—	—	—	—	—	—	—	—
IT	1.60	43.0	6.00	47.0	1.50	52.0	76.0	45.0	63.0	33.0	10.0	10.5	27.0	34.0	37.0	22.0	9.00
LA	1.30	48.0	5.20	37.0	2.00	53.0	62.0	40.0	50.0	—	—	—	—	—	—	—	—
LC	1.80	51.0	7.00	65.0	1.20	51.0	95.0	50.0	76.0	28.0	8.5	10.5	26.0	34.0	35.0	24.0	14.00
LV	1.60	49.0	7.00	49.0	1.50	51.0	79.0	41.0	57.0	34.0	12.0	10.0	25.0	32.0	34.0	22.0	11.00
KO	1.20	41.3	5.40	39.2	—	48.4	75.0	50.0	—	—	—	—	—	—	—	—	—
MD	2.20	69.2	6.30	58.7	1.90	55.2	105.2	52.5	90.2	37.6	10.8	9.0	23.2	28.6	31.8	19.2	8.30
NA	1.76	42.7	6.10	28.0	—	51.0	71.0	40.0	—	—	—	—	—	—	—	—	—
NE	1.40	43.0	5.10	40.0	1.60	55.0	92.0	42.0	64.0	—	—	—	—	—	—	—	—
OC	2.30	54.0	9.00	70.0	1.30	51.0	75.0	49.0	64.0	32.0	7.0	—	—	—	—	26.0	11.00
OP	1.80	59.5	7.45	56.0	1.95	57.5	66.0	36.0	49.5	33.0	6.5	9.0	17.0	24.5	30.5	16.0	6.70
OY	1.60	47.0	5.50	51.0	1.60	52.5	82.0	45.0	71.0	33.0	9.0	10.0	24.0	31.0	34.0	20.0	9.00
PA	2.10	49.6	6.10	60.5	1.10	52.1	103.5	56.7	79.6	36.1	9.0	14.6	31.7	40.1	43.4	32.4	7.00
PC	2.26	67.0	6.70	79.0	1.33	57.3	80.0	46.0	64.0	28.0	—	—	—	—	—	—	—
PE	1.70	49.0	6.70	56.0	1.40	52.0	88.0	49.0	72.0	30.0	8.0	10.0	26.0	29.0	33.0	21.0	9.00
PF	1.90	62.0	6.80	51.0	1.90	53.0	83.0	52.0	76.0	40.0	8.0	—	—	—	—	21.0	8.50
PF(pv)	2.00	58.0	7.00	54.0	1.80	53.0	85.0	50.5	74.0	37.0	8.0	—	—	—	—	21.0	8.50
PS	1.90	44.3	5.80	92.6	0.80	54.5	111.0	56.5	88.0	20.5	8.5	11.0	30.5	37.0	43.0	27.0	17.50
PT	1.90	64.0	7.00	63.0	1.60	56.0	86.0	48.0	77.0	31.0	—	—	—	—	—	—	—
PV	1.60	49.1	5.80	66.2	1.20	53.0	93.0	49.0	76.0	24.5	5.0	10.0	25.0	28.0	33.0	25.5	10.00
RV	1.96	41.8	6.28	55.5	1.38	52.2	96.0	51.0	76.0	35.0	—	10.0	—	—	—	26.0	—

SH	1.80	40.0	5.20	68.0	0.70	55.0	107.0	58.0	94.0	24.0	10.0	11.0	31.0	40.0	44.0	32.0	16.00
SH(P)	1.70	41.0	5.70	60.0	0.90	53.0	100.0	55.0	84.0	26.0	10.0	11.0	31.0	39.0	42.0	29.0	15.00
SL	2.00	39.9	5.40	72.5	0.80	54.0	126.0	69.0	—	27.5	—	—	—	—	—	—	—
SM	1.90	71.0	7.20	67.0	1.70	53.0	66.0	39.0	51.0	29.0	7.0	9.0	18.0	24.0	27.0	17.0	8.00
TA	1.30	38.0	5.70	40.0	1.60	54.0	81.0	45.0	62.0	33.0	13.0	12.0	29.0	33.0	36.0	21.0	8.00
TH	2.00	54.0	7.30	66.0	1.30	51.0	79.0	49.0	64.0	31.0	6.0	11.0	25.0	33.0	38.0	24.0	10.00
TH(GC)	2.10	47.0	6.60	71.0	1.30	50.0	85.0	53.0	71.0	29.0	7.0	11.0	27.0	39.0	44.0	23.0	9.00
TH(MI)	1.90	47.0	6.20	62.0	1.30	52.0	85.0	52.0	73.0	32.0	6.0	11.0	26.0	35.0	41.0	24.0	10.00
TN	1.80	46.0	7.30	61.0	1.50	51.0	76.0	45.0	60.0	29.0	8.0	9.0	23.0	33.0	38.0	22.0	8.00
TY	2.30	50.7	7.10	83.0	0.90	49.7	94.0	58.5	78.3	27.7	10.3	13.8	32.1	39.9	45.1	30.4	19.50
UT	2.10	63.0	6.70	64.0	1.40	54.0	93.0	49.0	81.0	33.0	5.0	11.0	24.0	29.0	34.0	23.0	8.00

† L = body length (mm); A, B, C, V = de Man's a, b, c, V ratios; ODS = odontostyle length (μm); OPH = odontophore length (μm); ORAP = oral aperture to guiding ring distance (μm); TAIL = tail length (μm); J = length of the jaline portion of tail (μm); DLIP, DGR, DBOE, DV, DA, and DBJ = body diameters at lip region, at guiding ring level, at base of esophagous, at vulva, at anus, and at beginning of J, respectively (μm).

‡ Population abbreviations are listed in Table 2.

Results

The correlation coefficients of the variables used for PCA are listed in Table 4. The variance associated with the selected first three principal components was 87.7% of the total variance (Table 5).

As shown in the dendrogram (Fig. 1), HCA indicated the occurrence of five tentative subgroups. These five subgroups are delimited on the scatterplot (Figs. 2,3). These tentative subgroups include the i) *X. brevicolle* subgroup (seven species, Table 6), with a body length of ca. 1.9 mm, V of 53%, and odontostyle length of 106 μm; ii) *X. americanum* subgroup (18 species, Table 7, including the atypical *X. brevicolle* population from Viçosa), with a total body length of ca. 1.8 mm, V of 51%, and odontostyle length of 85 μm; iii) *X. taylori* subgroup (two species, Table 8), with a total body length of 2.3 mm, V of 50%, and odontostyle length of 85 μm; iv) *X. pachtaicum* subgroup (four species, Table 9), with a total body length of ca. 2 mm, V of 55%, and odontostyle length of 86 μm; and v) *X. lambertii* subgroup (five species, Table 10), with total body length of ca. 1.4 mm, V of 52%, and odontostyle length of 76 μm.

Discussion

Generally, HCA placed populations of the same species into the same subgroup, as with the topotype and Campinas populations of *X. brevicolle.* The two populations of *X. sheri* were placed into the *X. brevicolle* subgroup. The two populations of *X. diffusum,* the three of *X. thornei,* the two of *X. floridae,* the two of *X. californicum,* the two of *X. americanum,* and the two of *X. pacificum* all fell into the *X. americanum* subgroup, although conspecific populations were often located far apart: e.g., the *X. americanum, X. thornei,* and *X. diffusum* populations.

The population of *X. brevicolle* from Viçosa was placed in the *X. americanum* subgroup instead of the *X. brevicolle* subgroup: this may be an atypical population, as indicated by the lip region and tail shape

TABLE 4. Correlation coefficients among the variables chosen for principal component analysis of *Xiphinema americanum*-group populations.

	L†	A	B	C	V	ODS
A	0.5586					
B	0.5360	0.5375				
C	0.6742	0.1837	0.2302			
V	0.1683	0.3657	−0.0948	0.1132		
ODS	0.3939	−0.1438	−0.3157	0.5431	0.2110	
OPH	0.4052	−0.2611	−0.2255	0.6029	−0.0898	0.8344

† L = body length (mm); A, B, C, V = de Man's a, b, c, V ratios; ODS = odontostyle length (μm); OPH = odontophore length (μm).

similar to those of *X. brevicolle* and biometrics close to those of *X. diffusum* (15). Once considered identical to *X. brevicolle* (20), *X. inaequale* was placed in the *X. brevicolle* subgroup but at a conspicuous distance from the two *X. brevicolle* populations within the subgroup (Fig. 1).

Xiphinema diffusum (in the *X. americanum* subgroup) is widespread in Mauritius, a small island from where *X. silvaticum* (*X. brevicolle* subgroup) was also described. *Xiphinema diffusum* has been regarded as a possible synonym of *X. brevicolle* (11), but the two species differ in morphology (15). The HCA indicated that *X. diffusum* seems more closely related to *X. americanum* than to *X. brevicolle.*

It has been suggested that *X. intermedium, X. laevistriatum, X. oxycaudatum,* and *X. tenuicutis* are junior synonyms of *X. americanum* (6). These species are in the *X. americanum* subgroup but are often clustered between the two populations of *X. americanum* sensu stricto. The differential diagnosis of *X. intermedium* (12) indicated that this species is intermediate between *X. americanum* and *X. oxycaudatum;* HCA also indicated that *X. intermedium* appears closely related to these two species, but less closely to *X. americanum* than to *X. oxycaudatum.*

Xiphinema neoamericanum, regarded as a *species inquirenda* (25), falls in the *X. lambertii* subgroup, which is composed primarily of species described from India.

Xiphinema neoelongatum, a junior synonym of *X. pachtaicum* (24), falls in the *X. lambertii* subgroup, clearly distinct from the species included in the *X. pachtaicum* subgroup.

The description of *X. thornei* (17) included a statement that the authors (5), while describing *X. occiduum,* may have worked with populations belonging to both species. The HCA placed *X. thornei* in the *X. americanum* subgroup and *X. occiduum* in the *X. taylori* subgroup.

The original description of *X. bricolense* indicated that it was similar to both *X. thornei* and *X. occiduum.* The HCA, however,

TABLE 5. Eigenvalues of the correlation matrix generated during principal component analysis of *Xiphinema americanum*-group populations.

Component	Eigenvalue	Difference	Proportion	Cumulative
PRIN1	2.79719	0.61623	0.399599	0.39960
PRIN2	2.18096	1.01827	0.311565	0.71116
PRIN3	1.16269	0.80659	0.166098	0.87726
PRIN4	0.35609	0.08951	0.050871	0.92813
PRIN5	0.26659	0.13485	0.038084	0.96622
PRIN6	0.13174	0.02699	0.018819	0.98504
PRIN7	0.10475	—	0.014964	1.00000

PRIN1–PRIN7 = Principal components generated from the correlation matrix.

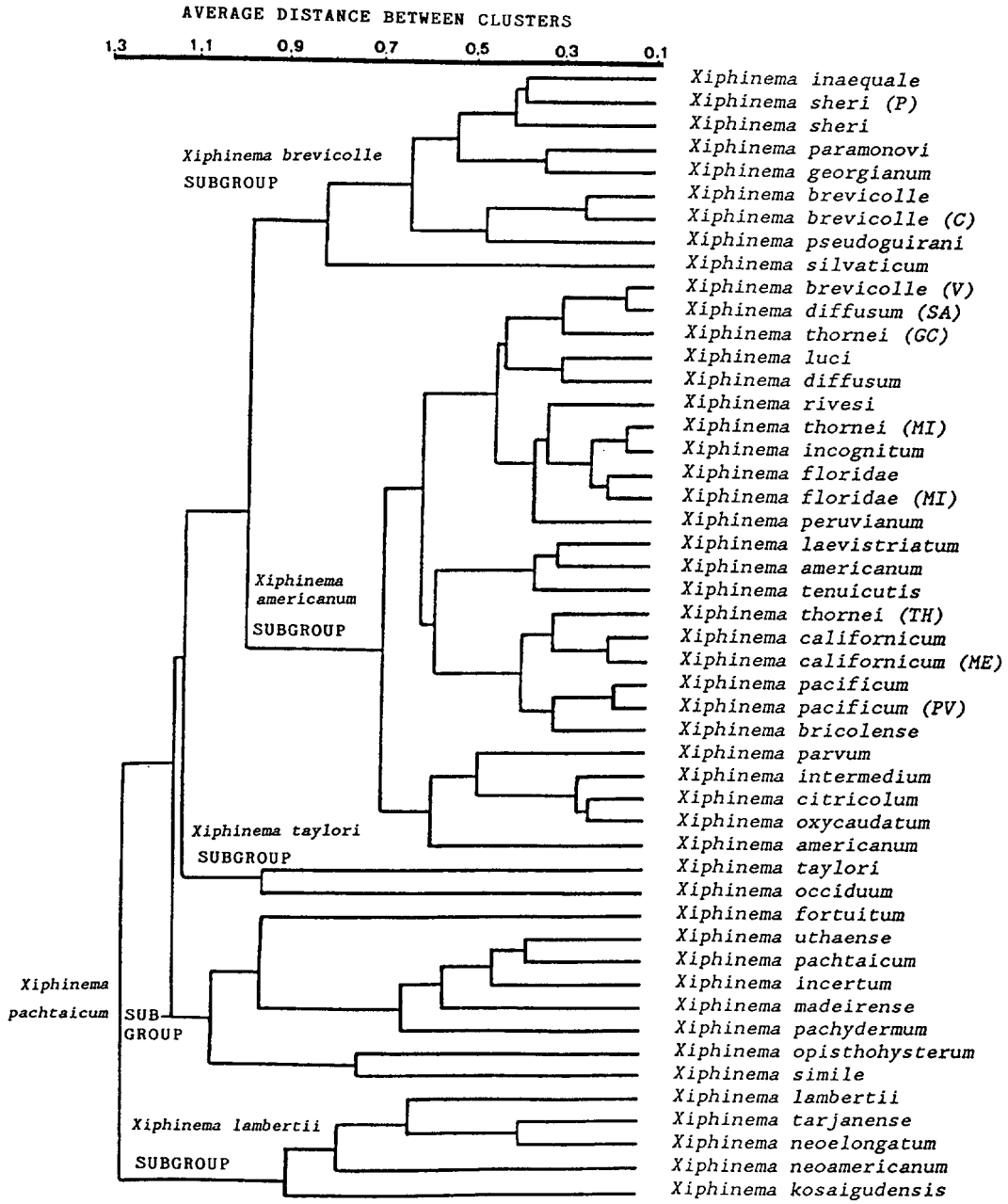

FIG. 1. Dendrogram showing the clustering of 49 populations of *Xiphinema americanum*-group species, analyzed by hierarchical cluster analysis of morphometric variables, and the average distance between clusters.

placed *X. bricolense* and *X. thornei* in the *X. americanum* subgroup but *X. occiduum* in the *X. taylori* subgroup.

Xiphinema pachtaicum and *X. opisthohysterum* both were placed by HCA into the *X. pachtaicum* subgroup. Two other members of this subgroup are *X. incertum* and *X. simile.*

The type population of *X. parvum* was once regarded merely as a variant population within *X. diffusum* (12). Our HCA analysis included both in the *X. americanum* subgroup as clearly distinct populations, as already demonstrated (15).

Both populations of *X. californicum,* con-

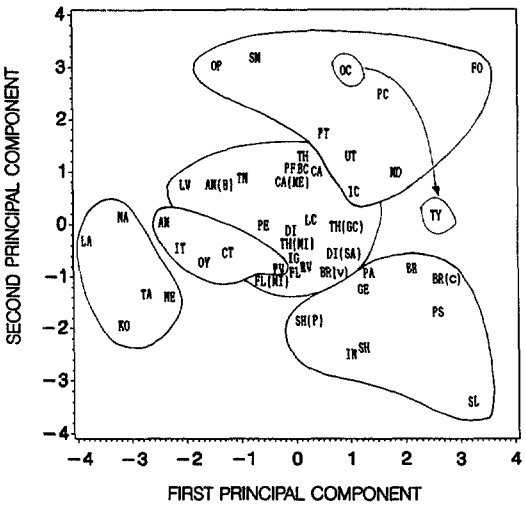

FIG. 2. Scatterplot of 49 populations of *Xiphinema americanum* group species on the first and second principal component axis. Population codes as indicated in Figure 1. PF and PF(PV) coincide.

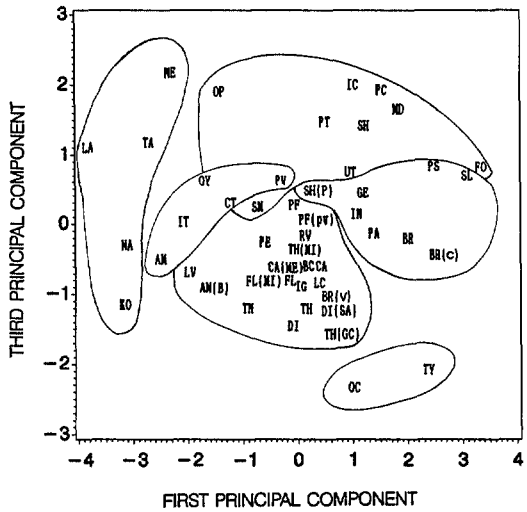

FIG. 3. Scatterplot of 49 populations of *Xiphinema americanum* group species on the first and third principal component axis. Population codes as indicated in Figure 1.

sidered by some authors (8) as a synonym of *X. americanum,* fell into the *X. americanum* subgroup as did *X. pacificum.*

The subgroups established during our HCA analysis do not coincide fully with the geographical distribution of the 39 *X. americanum*-group species. However, several interesting correlations between geographical distribution and morphometric subgroups did exist.

The seven species of the *X. brevicolle* subgroup (I), are scattered. Two species have been described only from Africa (*X. pseudoguirani* and *X. silvaticum*), one from Europe (*X. paramonovi*), one from South America (*X. brevicolle*), and one from Asia (*X. sheri*), with *X. inaequale* occurring in Asia and South America and *X. georgianum* in North and South America.

The *X. americanum* subgroup (II) includes a population of *X. brevicolle* from South America (Brazil) and 17 other spe-

TABLE 6. Morphometric values of the populations placed in the *Xiphinema brevicolle* subgroup (I) by hierarchical cluster analysis of *X. americanum*-group populations.

Population	L†	A	B	C	V	ODS	OPH
X. inaequale	1.78	43.4	5.2	68.4	52.0	104.0	60.0
X. brevicolle (topotypes)	2.10	44.5	6.4	77.8	53.0	101.9	57.0
X. brevicolle BR(C)	1.90	44.9	6.1	73.7	50.5	89.9	53.0
X. paramonovi	2.10	49.6	6.1	60.5	52.1	103.5	56.7
X. georgianum	1.90	47.0	6.1	64.0	53.0	112.0	53.0
X. silvaticum	2.00	39.9	5.4	72.5	54.0	126.0	69.0
X. sheri	1.80	40.0	5.2	68.0	55.0	107.0	58.0
X. sheri SH(P)	1.70	41.0	5.7	60.0	53.0	100.0	55.0
X. pseudoguirani	1.90	44.3	5.8	92.6	54.5	111.0	56.5
Minimum	1.70	39.9	5.2	60.0	50.5	89.9	53.0
Maximum	2.10	49.6	6.4	92.6	55.0	126.0	69.0
Mean	1.91	43.8	5.7	70.8	53.0	106.1	57.5
Standard deviation	0.14	3.2	0.4	10.1	1.3	9.9	4.8
Standard error	0.05	1.0	0.1	3.3	0.4	3.3	1.6

† L = body length (mm); A, B, C, V = de Man's a, b, c, V ratios; ODS = odontostyle length (μm); OPH = odontophore length (μm).

TABLE 7. Morphometric values of the populations placed in the *Xiphinema americanum* subgroup (II) by hierarchical cluster analysis of *X. americanum*-group populations.

Population	L	A	B	C	V	ODS	OPH
X. brevicolle BR(V)	2.10	47.9	6.20	86.9	52.3	104.5	58.6
X. laevistriatum	1.60	49.0	7.00	49.0	51.0	79.0	41.0
X. luci	1.80	51.0	7.00	65.0	51.0	95.0	50.0
X. rivesi	1.96	41.8	6.28	55.5	52.2	96.0	51.0
X. diffusum	1.70	47.0	6.90	72.0	50.0	87.0	50.0
X. diffusum DI(SA)	1.90	44.8	6.40	79.5	50.7	88.4	53.2
X. thornei	2.00	54.0	7.30	66.0	51.0	79.0	49.0
X. thornei TH(GC)	2.10	47.0	6.60	71.0	50.0	85.0	53.0
X. thornei TH(MI)	1.90	47.0	6.20	62.0	52.0	85.0	52.0
X. incognitum	1.90	45.0	6.30	62.0	51.0	87.0	52.0
X. parvum	1.60	49.1	5.80	66.2	53.0	93.0	49.0
X. floridae	1.80	44.0	6.30	59.0	51.0	90.0	54.0
X. floridae FL(MI)	1.70	43.0	6.00	63.0	51.0	87.0	52.0
X. peruvianum	1.70	49.0	6.70	56.0	52.0	88.0	49.0
X. intermedium	1.60	43.0	6.00	47.0	52.0	76.0	45.0
X. citricolum	1.70	45.5	6.00	49.0	52.5	86.0	47.0
X. californicum	2.00	60.0	6.80	63.0	51.0	90.0	48.0
X. californicum CA(ME)	1.90	56.0	6.90	58.0	51.0	86.0	48.0
X. americanum	1.50	54.0	5.80	49.0	50.0	69.0	44.0
X. americanum AM(B)	1.70	50.0	7.00	48.0	51.0	73.0	47.0
X. pacificum	1.90	62.0	6.80	51.0	53.0	83.0	52.0
X. pacificum PF(PV)	2.00	58.0	7.00	54.0	53.0	85.0	50.5
X. bricolense	1.90	56.0	7.50	57.0	52.0	87.0	51.0
X. oxycaudatum	1.60	47.0	5.50	51.0	52.5	82.0	45.0
X. tenuicutis	1.80	46.0	7.30	61.0	51.0	76.0	45.0
Minimum	1.50	41.8	5.50	47.0	50.0	69.0	41.0
Maximum	2.10	62.0	7.50	86.9	53.0	104.5	58.6
Mean	1.81	49.4	6.54	60.0	51.4	85.4	49.4
Standard deviation	0.17	5.5	0.53	10.0	0.9	7.6	3.7
Standard error	0.03	1.1	0.11	2.0	0.1	1.5	0.7

† L = body length (mm); A, B, C, V = de Man's a, b, c, V ratios; ODS = odontostyle length (μm); OPH = odontophore length (μm).

cies. Seven have been described only from North America (*X. americanum, X. bricolense, X. citricolum, X. laevistriatum, X. pacificum, X. tenuicutis* and *X. thornei*), one from Jamaica (*X. parvum*), one from South America (*X. peruvianum*), one from Asia (*X. incognitum*), and two from Africa (*X. luci* and *X. oxycaudatum*). In addition, *X. californicum* and *X. floridae* occur in North and South America, *X. intermedium* occurs in North America and Asia, *X. rivesi* occurs in Europe and North America, and *X. dif-*

TABLE 8. Morphometric values of the populations placed in the *Xiphinema taylori* subgroup (III) by hierarchical cluster analysis of *X. americanum*-group populations.

Population	L†	A	B	C	V	ODS	OPH
X. taylori	2.3	50.7	7.1	83.0	49.7	94.0	58.5
X. occiduum	2.3	54.0	9.0	70.0	51.0	75.0	49.0
Minimum	2.3	50.7	7.1	70.0	49.7	75.0	49.0
Maximum	2.3	54.0	9.0	83.0	51.0	94.0	58.5
Mean	2.3	52.3	8.0	76.5	50.3	84.5	53.7
Standard deviation	0.0	2.3	1.3	9.1	0.9	13.4	6.7
Standard error	0.0	1.6	0.9	6.5	0.6	9.5	4.7

† L = body length (mm); A, B, C, V = de Man's a, b, c, V ratios; ODS = odontostyle length (μm); OPH = odontophore length (μm).

TABLE 9. Morphometric values of the populations placed in the *Xiphinema pachtaicum* subgroup (IV) by hierarchical cluster analysis of *X. americanum*-group populations.

Population	L†	A	B	C	V	ODS	OPH
X. fortuitum	2.60	83.4	7.10	75.7	54.0	102.0	50.6
X. opisthohysterum	1.80	59.5	7.45	56.0	57.5	66.0	36.0
X. simile	1.90	71.0	7.20	67.0	53.0	66.0	39.0
X. utahense	2.10	63.0	6.70	64.0	54.0	93.0	49.0
X. incertum	1.90	57.0	6.40	69.0	57.0	92.0	51.0
X. pachtaicum	1.90	64.0	7.00	63.0	56.0	86.0	48.0
X. pachydermum	2.26	67.0	6.70	79.0	57.3	80.0	46.0
X. medeirense	2.20	69.2	6.30	58.7	55.2	105.2	52.5
Minimum	1.8	57.0	6.3	56.0	53.0	66.0	36.0
Maximum	2.6	83.4	7.4	79.0	57.5	105.2	52.5
Mean	2.0	66.7	6.8	66.5	55.5	86.2	46.5
Standard deviation	0.2	8.2	0.4	7.9	1.7	14.8	5.9
Standard error	0.1	2.9	0.1	2.7	0.6	5.2	2.1

† L = body length (mm); A, B, C, V = de Man's a, b, c, V ratios; ODS = odontostyle length (μm); OPH = odontophore length (μm).

fusum is widespread in North America, Africa, the Middle East, and Southeast Asia.

The *X. taylori* subgroup (III) is composed of only two species, *X. taylori* (common in Italy and Central Europe) and *X. occiduum* (never observed outside North America).

Of the eight species included in the *X. pachtaicum* subgroup (IV), five have been described from Europe only (*X. fortuitum, X. incertum, X. madeirense, X. pachydermum,* and *X. simile*), one from North America (*X. utahense*), and one from Asia (*X. opisthohysterum*). *Xiphinema pachtaicum* is widespread in the Mediterranean basin and present in many other regions.

The *X. lambertii* subgroup (V) is composed of four species reported from India only (*X. lambertii, X. kosaigudensis, X. neoamericanum,* and *X. neoelongatum*) and one species reported from North America only (*X. tarjanense*).

Therefore, although HCA morphological groupings based on the restricted number of variables available for all species do not fully coincide with geographical distributions, the *X. americanum* subgroup consists primarily of American species, the *X. pachtaicum* subgroup seems primarily European, and the *X. lambertii* subgroup consists of mainly Asian species.

Finally, although the present approach indicates or suggests relationships in the morphometrics of more or less geographically separated species, it does not substantially facilitate species identification,

TABLE 10. Morphometric values of the populations placed in the *Xiphinema lambertii* subgroup (V) by hierarchical cluster analysis of *X. americanum*-group populations.

Population	L†	A	B	C	V	ODS	OPH
X. lambertii	1.30	48.0	5.2	37.0	53.0	62.0	40.0
X. neoamericanum	1.76	42.7	6.1	28.0	51.0	71.0	40.0
X. kosaigudensis	1.20	41.3	5.4	39.2	48.4	75.0	50.0
X. tarjanense	1.30	38.0	5.7	40.0	54.0	81.0	45.0
X. neoelongatum	1.40	43.0	5.1	40.0	55.0	92.0	42.0
Minimum	1.20	38.0	5.1	28.0	48.4	62.0	40.0
Maximum	1.76	48.0	6.1	40.0	55.0	92.0	50.0
Mean	1.39	42.6	5.5	36.8	52.2	76.2	43.3
Standard deviation	0.22	3.6	0.4	5.0	2.6	11.2	4.2
Standard error	0.10	1.6	0.1	2.2	1.1	5.0	1.8

† L = body length (mm); A, B, C, V = de Man's a, b, c, V ratios; ODS = odontostyle length (μm); OPH = odontophore length (μm).

for which the traditional way of using a dichotomous key with the aid of single descriptions remains, in our opinion, the most efficient method.

Nevertheless, one might wonder whether HCA would provide a better separation between subgroups or species if other characters were included among the variables, such as morphological (lip region and tail shape), biological (number of juvenile stages [9]), and biomolecular (restriction fragment length [34]) characters. Increasing the number of populations analyzed would perhaps not simplify this problem, which probably can be better resolved by comparing only type populations.

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