2019 Statistics of embryo production and transfer in domestic farm animals

Divergent trends for IVD and IVP embryos

By Joao Viana, Chair – IETS Data Retrieval Committee (henrique.viana@embrapa.br)
In: Embryo Technology Newsletter, v. 38, n.4, 2020

1. Executive summary

The International Embryo Technology Society (IETS) Data Retrieval Committee presents the 29th annual report of data collected globally in 2020 on embryo transfer (ET) activities during 2019. We observed a slight reduction in the number of countries reporting data in 2020, compared with 2019 (39 *vs.* 42; Table 1). This occurred mainly in Europe (no ET activity was reported by Bosnia and Herzegovina, Estonia, Hungary, Poland, and Ukraine). Asia accounted for a major gap in the world numbers, as ET reports were received from only two out of 48 countries in that regions, and we miss data from countries that have either large farm animal herds (e.g., India and China) or active ET industry (Japan). Data from Central America was pooled with South America. However, the absence of ET activity in many Caribbean countries resulted in a relatively low percentage of countries reporting data in these regions (25.0%). Actually, eight out of 13 (61.5%) South American countries submitted ET data in 2020.

Table 1. Number and proportion of countries submitting ET data, by region and species

Region	Cattle		Other (IVD + IVP) [1]				% countries
	IVD	IVP	Horses	Sheep	Goats	Other[2]	within region
Africa	1	1	0	0	0	0	1.9% (1/54)
Asia	1	0	0	0	0	1	4.2% (2/48)
Europe	21	10	6	8	2	3	46.8% (22/47)
North America	3	3	3	2	2	3	100.0% (03/03)
Oceania	0	1	0	1	0	1	14.3% (2/14)
South America[3]	3	8	2	1	1	0	25.0% (9/36)
Total	**29**	**23**	**11**	**12**	**5**	**8**	**19.3% (39/202)**

[1] IVD: *in vivo* derived; IVP: *in vitro* produced
[2] Cervids, swine, buffalo
[3] South and Central America

The embryo industry numbers in 2019 for the four most representative farm animal species are summarized in Table 2 (total embryo production/collection) and Table 3 (numbers of transferred embryos). For the first time since 2014, the total recorded bovine embryos decreased, compared with the previous year (1,419,336 *vs.* 1,499,367 in 2018; -5.3%). Divergent trends were, however, observed for *in vivo* derived (IVD) and *in vitro* produced (IVP) embryos, as the reduction observed in totals was driven by a significant decrease in the number of IVD embryos (378,769 *vs.* 469,967 in 2018, -17.5%), whereas the production of *in vitro* embryos reached a plateau (1,031,567 *vs.* 1,029,400 in 2018; +0.2%). The decline in the collection of bovine IVD embryos was a widespread phenomenon, demonstrated by decreased numbers in all regions. The divergent trends for IVD and IVP embryos in cattle resulted in an increase in the proportion of IVP embryos, which accounted for 72.7% of all transferable embryos in cattle in 2019, compared with 68.7% in 2018. Among the 36 countries with cattle ET data, 23 (63.9%) reported the use of *in vitro* embryo production (IVEP).

A similar scenario was observed in sheep and horses. Although in both species the total transferable embryos increased (+19.9% and +31.6%; respectively), the most significant changes were observed in the number of IVP embryos (from 2,453 to 6,303 in horses, +157.0%;

and from 512 to 1,137 in sheep, +122.1%; comparing 2018 with 2019). In 2019, IVP embryos accounted for 22.1% of all horse embryos and for 4.8% of all sheep embryos, compared with 10.3% and 2.9% in 2018, respectively. This scenario was not observed for goat embryos, in which both the numbers of IVD and IVP embryos decreased, compared with 2018 (-0.9% and -8.6%, respectively). Nevertheless, only five countries reported ET data in goats, suggesting underreported numbers and preclude the correct analysis of trends in this species.

Table 2. Total production (transferrable embryos) of IVD and IVP embryos in 2019 in cattle, sheep, goats, and horses, according to region

Region	Cattle		Horses		Sheep		Goats	
	IVD	IVP	IVD	IVP	IVD	IVP	IVD	IVP
Africa	4,413	3,645	0	0	0	0	0	0
Asia	94	0	0	0	0	0	0	0
Europe	124,892	62,009	1,044	3,722	1,078	142	897	748
North America	218,926	525,078	1,665	1,015	8,295	914	7,754	0
Oceania	0	10,480	0	0	2,805	0	0	0
South America	39,444	430,355	19,489	1,566	10,196	81	74	0
Total	**387,769**	**1,031,567**	**22,198**	**6,303**	**22,374**	**1,137**	**8,725**	**748**

Interestingly, only a small reduction in the number of bovine embryos transferred was observed in 2019 (1,117,151 *vs.* 1,129,041 in 2018; -1.1%). Although the proportion of IVD embryos collected and transferred decreased at similar rates (-17.5% and -17.1%, respectively), the number of transferred IVP embryos increased 7.3%. In fact, more IVP embryos were actually transferred in 2019, compared with 2018 (77.3% *vs.* 72.2%, respectively), and this trend was observed for all regions. The difference between the number of produced and transferred embryos was lesser in South America and this region leads the number of transfers, in spite of producing lesser total embryos than North America, similar to the 2018 scenario. We did not detect a significant change in the use of cryopreservation in IVD embryos (60.8% *vs.* 60.1% for 2019 and 2018, respectively). Conversely, the proportion of frozen IVP embryos transferred increased from 26.8% in 2018 to 43.9% in 2019, resuming the trend observed from 2013 until 2017.

Table 3. Transfers of IVD and IVP embryos in 2019 in cattle, sheep, goats, and horses, according to region

Region	Cattle		Horses		Sheep		Goats	
	IVD	IVP	IVD	IVP	IVD	IVP	IVD	IVP
Africa	3,077	3,233	0	0	0	0	0	0
Asia	44	0	0	0	0	0	0	0
Europe	99,697	47,010	1,183	561	1,904	142	64	33
North America	181,301	335,758	3,106	1,558	7,675	0	7,102	914
Oceania	0	10,031	0	0	2,735	0	0	0
South America	35,842	401,158	19,257	1,445	10,196	81	74	0
Total	**319,961**	**797,190**	**23,546**	**3,564**	**22,510**	**223**	**7,240**	**947**

In summary, in 2019 the world cattle embryo industry was characterized by divergent trends: a decrease in the production and transfers of IVD embryos, contrasting with an increase in the number of transfers of IVP embryos. The increase in the proportion of IVP embryos actually transferred, as well as in the use of cryopreservation, but not in total embryo production, suggests progress in IVEP systems adopted worldwide. Moreover, the number of IVP embryos also increased significantly in sheep and horses.

2. Introduction

The Data Retrieval Committee (DRC) is the committee of the International Embryo Technology Society (IETS) in charge of gathering, organizing, and publishing the statistics of the embryo industry in domestic farm animals. This year, we present our 29th annual report showing data on global activities related to *in vivo* and *in vitro* embryo collection and transfer in 2019. The results shown in the present report will be further discussed by the DRC members, and will support the decisions and strategies for embryo data collection in the following years.

3. Methodology

Data collection followed the standard methodology used in previous reports, as described by Perry (2014). In summary, embryo technology activity was either reported for each country by a national data collector or reported individually by practitioners or representatives of commercial companies (e.g., *in vitro* embryo production [IVEP] laboratories). In several countries, the data collector is linked to the national embryo transfer/technology association: Argentina (Sociedad Argentina de Tecnologías Embrionarias, SATE), Brazil (Sociedade Brasileira de Tecnologia de Embriões, SBTE), Canada (Canadian Embryo Transfer Association, CETA), Mexico (Mexican Embryo Transfer Society, META), Paraguay (Asociación Paraguaya de Reproducción Animal, APRA), Peru (Asociación Peruana de Reproducción Animal, ASPRA), the United States (American Embryo Transfer Association, AETA). For the Member States of the European Union and other European countries, data is submitted by a regional collector on behalf of the Association of Embryo Technology in Europe (AETE). Data was also reported by ET teams or companies working abroad. In a few countries, this was the sole source of information on embryo activity. In the case of similar data reported by a local representative, however, data coming from such teams or companies were not used, to avoid double-reporting. The updated list of regional data collectors and local collaborators is shown in Appendix 1.

Data was directly uploaded into the IETS website by the national collector or sent to the Chair of the DRC. The software managing the database generated MS Excel .csv files with data organized by criteria defined in the data submission form. A summary of the results is shown in Tables 4 to 14, according to region, technology (*in vivo*-derived [IVD] or *in vitro*-produced [IVP]), and species. South American numbers include those collected from South and Central America countries. Detailed country information will be available in the Appendix 2 to 6. Data was also used to build historical series, shown in Figures 2 to 5.

4. Results

Data retrieval

The DRC have recovered ET data from Europe and Americas consistently over the past decades, thanks mainly to the efforts of local ET societies and to the engagement of local collectors and, in the case of IVP embryos, to the IVEP laboratories that kindly opened their numbers. The comprehensiveness of ET data from these regions allowed the characterization of the main trends of ET industry over the years. In 2019, we obtained ET records from 39 countries (Figure 1), including all in North America (3/3, 100%), the majority of South America (8/13, 61.5% [excluding Central America]), and a representative number of countries in Europe (22/47, 46.8%). A small fluctuation in the number of countries reporting data was expected, and reflects mostly changes in areas with less active ET industry, as the Caribbean and East Europe, rather than problems in recovering and reporting data. In fact, the European countries that reported data in 2018 but not in 2019 accounted for only 1.3% (2,565/193,096) of all

embryos recorded in Europe in 2018. Similarly, ET is still not used or is incipient in most of African countries, except South Africa, and the low numbers from this continent are likely to reflect the real picture of that region.

Conversely, erratic data report from Oceania and Asia blur the scenario in these regions. A number of reasons may explain this situation, including cultural and regulatory aspects, lack of ET societies, or low engagement of the scientific community. Japan, for example, has a known active ET industry, but due to changes in internal policies has stopped reporting data since 2016, resulting in a significant drop in Asia numbers. Teams working abroad submitted some ET data from Asia and Oceania, giving a valuable contribution to fill the gaps in the numbers from these regions.

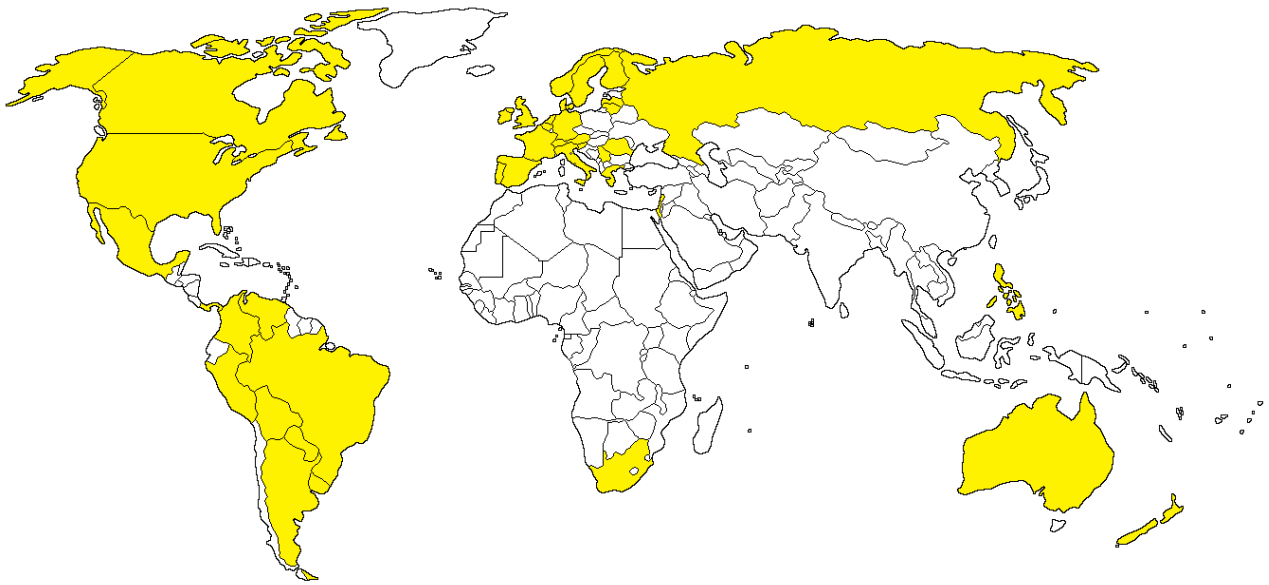

Figure 1. World political map showing the countries that submitted 2019 ET data

4.1 Embryo industry in numbers

4.1.1 Cattle, IVD

In 2019, a total of 1,480,821 transferrable embryos were collected or produced, which represents a reduction compared with 2018 (-5.3%) – the first since 2014. Nevertheless, the total remained above 1,4 million, as observed since 2017. In regard to type of embryo, IVD and IVP embryos represented 27.3% (387,769) and 72.7% (1,031,769) of the total, respectively.

Table 4. Collection of bovine *in vivo* derived [IVD] embryos per region

Region/ Country	Flushes			Collected					
				Ova			Transferrable embryos		
	Dairy	Beef	Total	Dairy	Beef	Total	Dairy	Beef	Total
Africa	6	1,065	1,071	83	6,533	6,616	27	4,386	4,413
Asia	26	0	26	115	0	115	94	0	94
Europe	14,746	4,592	19,338	147,464	39,784	187,248	99,199	25,693	124,892
N America	12,896	20,993	33,889	123,321	261,867	385,188	69,289	149,637	218,926
Oceania	0	0	0	0	0	0	0	0	0
S America	2,040	4,124	6,164	16,633	40,950	57,583	14,668	24,776	39,444
Total	**29,714**	**30,774**	**60,488**	**287,616**	**349,134**	**636,750**	**183,277**	**204,492**	**387,769**

The number of flushes, ova, and transferrable embryos collected in 2019 according to region is shown in Table 4. The collection of *in vivo* embryos is still the most prevalent technology, and IVD embryos were reported by 29 out of 36 (80.1%) countries with ET data in cattle. However, the number of IVD embryos has been decreasing since 2015 and, in 2019, was 17.5% lower than 2018 (387,769 *vs.* 469,967, respectively), with a proportional decrease in the number of IVD transferred embryos (319,961 *vs.* 386,133; -17.1%, respectively). The reduction in the number of collected IVD embryos was a widespread phenomenon: -33.6% in Africa, -42.0% in Asia, -11.6% in Europe, -19.0% in North America, and -16.6% in South America. There was no major change in superovulation efficiency, as the estimated number of ova and transferable embryos per flush remained relatively constant (10.5 and 6.4 in 2019 *vs.* 10.2 and 6.2 in 2018, or 10.6 and 6.4 in 2017, respectively).

As observed in previous years, North America accounts for most of the IVD embryos collected (56.5%), leaded by the United States of America. Although the number of IVD embryos decreased 18.2% in the USA, compared with 2018 it still represents 43.3% of the world's total. Most of IVD embryos from North and South America were collected from beef breeds (68.3% and 62.8%, respectively), contrasting with a predominance of dairy breeds in Europe (99,199/124,892; 79.4%). The use of sex-sorted semen has been reported for 18.6% of the flushes, predominantly in dairy breeds (84.8%).

The transfers of IVD embryos in 2019 is shown in Table 5. A decrease in the number of IVD transferred embryos was also observed in all regions. However, significant changes did not occur neither in the proportion of transfers of frozen-thawed embryos (60.8% *vs.* 60.1% in 2018) nor in the proportion of total viable embryos that were actually transferred (82.5% *vs.* 82.2% in 2018). The predominance of transfers of cryopreserved embryos was reported mainly for beef breeds (69.5%, compared with 50.6% in dairy).

Table 5. Transfer of bovine *in vivo* derived [IVD] embryos by region

Region/ Country	Fresh			Frozen domestic			Frozen imported			Total ET
	Dairy	Beef	Unsorted	Dairy	Beef	Unsorted	Dairy	Beef	Unsorted	
Africa	5	1,323	0	9	1,098	0	0	642	0	3,077
Asia	42	0	0	2	0	0	0	0	0	44
Europe	39,986	4,609	0	34,003	18,107	0	2,095	897	0	99,697
N America	27,788	37,451	0	29,310	86,348	0	116	288	0	181,301
Oceania	0	0	0	0	0	0	0	0	0	0
S America	5,320	9,050	0	9,320	12,094	0	48	10	0	35,842
Total	**73,141**	**52,433**	**0**	**72,644**	**117,647**	**0**	**2,259**	**1,837**	**0**	**319,961**

4.1.2 Cattle, IVP

The number of countries reporting IVP embryos decreased from 29 in 2018 to 23 in 2019, driven mainly by a reduction in Europe (10 *vs.* 17 in 2018). Nevertheless, the number of IVP embryos in Europe remained stable (61,816 *vs.* 62,009 in 2018; -0.3%). IVEP was the main source of embryos in only half (9/18) of the countries reporting both IVD and IVP embryos; however, these countries accounted for 88.7% of all IVP cattle embryos reported worldwide in 2019. The production of embryos *in vitro* in 2019 is shown in Table 6 (OPU-collected oocytes) and Table 7 (abattoir-derived oocytes).

The number of IVP embryos stabilized in 2019 (1,031,567 *vs.* 1,029,400 in 2018; +0.2%), following a trend of slower growth rates observed in 2018 (+2.6%), compared with the previous rate observed from 2016 to 2017 (+48.9%). Minor changes were observed among the main representative regions, when numbers were compared with those from 2018: +0.3% in Europe, +4.2% in North America, -4.0% in South America. The USA leads IVEP worldwide, with a 5.0 % growth in 2019, similar to the growth observed in 2018 (5.3%). In the past five years,

IVEP in the USA increased 145.0%, an average 29.0% per year. On the other hand, the numbers from Brazil, the second country in total IVP embryos, decreased 13.1% in 2019 (299,870 *vs.* 345,125 in 2018). It is noteworthy that the difference between the number of recorded embryos and the number of ET sheaths sold in Brazil has increased over the past three years, suggesting a growing underreporting of ET activity – specially linked to the production of crossbred cattle that is not reported to the breeders' associations. In both USA and Brazil, most IVP embryos come from dairy breeds (58.8% and 53.6%; respectively).

Table 6. Production of embryos *in vitro* with OPU-collected oocytes by region

Region/	Donors			Oocytes			Transferrable embryos		
Country	Dairy	Beef	Total	Dairy	Beef	Total	Dairy	Beef	Total
Africa	0	365	365	0	14,544	14,544	0	3,272	3,272
Asia	0	0	0	0	0	0	0	0	0
Europe	15,411	2,523	17,934	189,270	37,474	226,744	48,478	11,433	59,911
N America	91,765	30,607	122,372	1,408,178	728,199	2,136,377	296,136	224,844	520,980
Oceania	560	1,307	1,867	10,903	25,441	36,344	3,144	7,336	10,480
S America	25,192	37,374	62,566	500,291	755,918	1,256,209	177,903	238,134	416,037
Total	**132,928**	**72,176**	**205,104**	**2,108,642**	**1,561,576**	**3,670,218**	**525,661**	**485,019**	**1,010,680**

A small decrease in the use of FSH stimulation before ovum pick-up (OPU) was observed in both Europe and North America (39.0% and 64.7% *vs.* 48.1% and 66.9% in 2018, respectively). Overall, FSH stimulation was used slightly more in dairy (51.2%) than in beef breeds (48.8%). Abattoir-derived oocytes accounted for a small proportion of IVP embryos: 3.4% in Europe, 0.8% in North America, and 3.3% in South America (overall 2.0%). However, the total number of embryos produced with such oocytes increased 85.9% (20,887 *vs.* 11,237 in 2018).

Table 7. Production of embryos *in vitro* with abattoir-derived oocytes by region

Region/	Donors			Oocytes			Transferrable embryos		
Country	Dairy	Beef	Total	Dairy	Beef	Total	Dairy	Beef	Total
Africa	0	143	143	0	2,343	2,343	0	373	373
Asia	0	0	0	0	0	0	0	0	0
Europe	662	204	866	7,499	2,017	9,516	1,449	649	2,098
N America	0	60	60	14,316	5,650	19,966	3,013	1,085	4,098
Oceania	0	0	0	0	0	0	0	0	0
S America	0	2,860	2,860	0	71,590	71,590	0	14,318	14,318
Total	**662**	**3,267**	**3,929**	**21,815**	**81,600**	**103,415**	**4,462**	**16,425**	**20,887**

The number of transfers of IVP embryos in 2019 is shown in Table 8. Important changes seem to be in progress in the IVEP industry. The number of IVP embryos actually transferred in 2019 increased, compared with 2018 (797,190 [77.3%] *vs.* 742,908 [72.2%], respectively), in spite of the stabilization (+0.2%) in the number of embryos produced. Once again, this trend was observed in all regions.

Additionally, the proportion of frozen-thawed IVP embryos transferred increased from 26.8% in 2018 to 43.9% in 2019, resuming the trend observed from 2013 to 2017. The proportion of IVP embryos transferred as frozen-thawed increased +43.8% in Africa, +0.1% in Europe, +13.2% in North America, +22.5% in Oceania, and +21.5% in South America.

Table 8. Transfer of bovine *in vitro* produced [IVP] embryos by region

Region/ Country	Embryos transferred							
	OPU				Abattoir			
	Fresh	Frozen		Total	Fresh	Frozen		Total
		Domestic	Foreign			Domestic	Foreign	
Africa	1,257	1,976	0	3,233	0	0	0	0
Asia	0	0	0	0	0	0	0	0
Europe	24,554	22,103	322	46,979	2	29	0	31
N America	183,229	150,412	53	333,694	84	1,980	0	2,064
Oceania	7,134	2,897	0	10,031	0	0	0	0
S America	222,302	169,900	0	392,202	8,751	205	0	8,956
Total	**438,476**	**347,288**	**375**	**786,139**	**8,837**	**2,214**	**0**	**11,051**

Data of embryos micro-manipulated for sexing or genotyping in 2019 is shown in Table 9. The number of sexed embryos decreased 32.3%, whereas the number of genotyped embryos increased 13.5%, compared with 2018. As the number of countries reporting micro-manipulation of embryos is historically low (seven in 2019), trends for IVD and IVP are deeply affected by the numbers of individual countries. For example, the dramatic increase in the number of genotyped IVD embryos (+275.2%) and the decrease in genotyped IVP (-58.8%) were mostly due to the numbers from The Netherlands (6,137 and 0 *vs.* 101 and 2,708 in 2018). On the other hand, Canada reported the same proportions of sexed and genotyped embryos that were IVD or IVP in 2019, compared with 2018, but in both cases the totals decreased (-45.1% and -45.3%, respectively).

Table 9. Micro-manipulation of bovine embryos for sexing and/or genotyping

Country	Sexed		Genotyped	
	IVD	IVP	IVD	IVP
Canada	251	3,358	0	3,343
Finland	92	77	92	77
France	2,595	0	2,526	0
Germany	0	0	206	154
Netherlands	0	0	6,137	0
Spain	0	92	0	92
United States	589	0	283	0
Total	**3,527**	**3,527**	**9,244**	**3,666**

4.1.3 Other species

The numbers of IVD and IVP embryos reported in 2019 in species other than cattle are shown in Tables 10 (sheep), 11 (goats), 12 (horses) and 13 (cervids, swine, and buffalo). A minor reduction occurred in the number of countries reporting sheep data (12 *vs.* 14 in 2018). Nevertheless, both the number of IVD and of IVP embryos increased in 2019, compared with 2018 (22,374 *vs.* 17,353 [+28.8%] and 1,137 *vs.* 512 [+122.1%], respectively). No IVP embryo was transferred as frozen-thawed, contrasting with 16.3% of the IVD embryos. Brazil reported the highest number of IVD embryos (10,196), while the USA leaded the number of IVP embryos (914), followed by Spain (142).

Table 10. Sheep: *in vivo* derived [IVD] and *in vitro* produced [IVP] embryo collections and transfers

Region/ Country	IVD Embryos					IVP embryos					
	Flushes	Embryos	Embryo transfer			Donors	Oocytes	Embryos	Embryo transfer		
			Fresh	Frozen					Fresh	Frozen	
				Domestic	Foreign					Domestic	Foreign
Europe											
Greece	12	33	0	0	0	0	0	0	0	0	0
Portugal	3	18	10	0	0	0	0	0	0	0	0
Romania	2	11	8	0	0	0	0	0	0	0	0
Russian Fed.	0	0	0	0	681	0	0	0	0	0	0
Serbia	0	0	12	0	0	0	0	0	0	0	0
Spain	12	111	53	12	0	15	340	142	142	0	0
Sweden	0	0	0	0	225	0	0	0	0	0	0
UK	166	905	895	8	0	0	0	0	0	0	0
Total	195	1,078	978	20	906	15	340	142	142	0	0
N America											
Canada	88	402	32	37	0	0	0	0	0	0	0
USA	1,275	7,893	7,213	181	212	0	0	914	0	0	0
Total	1,363	8,295	7,245	218	212	0	0	914	0	0	0
Oceania											
Australia	442	2,805	2,720	15	0	0	0	0	0	0	0
Total	442	2,805	2,720	15	0	0	0	0	0	0	0
S America											
Brazil	1,226	10,196	7,896	2,300	0	11	197	81	81	0	0
Total	1,226	10,196	7,896	2,300	0	11	197	81	81	0	0
Grand Total	**3,226**	**22,374**	**18,839**	**2,553**	**1,118**	**26**	**537**	**1,137**	**223**	**0**	**0**

Table 11. Goats: *in vivo* derived [IVD] and *in vitro* produced [IVP] embryo collections and transfers

Region/ Country	IVD Embryos					IVP embryos					
	Flushes	Embryos	Embryo transfer			Donors	Oocytes	Embryos	Embryo transfer		
			Fresh	Frozen					Fresh	Frozen	
				Domestic	Foreign					Domestic	Foreign
Europe											
Spain	105	846	0	0	0	31	1,631	748	21	12	0
UK	6	51	51	13	0	0	0	0	0	0	0
Total	111	897	51	13	0	31	1,631	748	21	12	0
N America											
Canada	12	40	18	0	0	0	0	0	0	0	0
USA	1,005	7,714	6,263	821	0	0	0	0	914	0	0
Total	1,017	7,754	6,281	821	0	0	0	0	914	0	0
S America											
Brazil	16	74	22	52	0	0	0	0	0	0	0
Total	16	74	22	52	0	0	0	0	0	0	0
Grand Total	**1,144**	**8,725**	**6,354**	**886**	**0**	**31**	**1,631**	**748**	**935**	**12**	**0**

Less countries reported ET data in goats in 2019 (5 *vs.* 7 in 2018). Differently from what was observed in sheep, however, both the number of IVD and IVP embryos decreased (8,725 and 748 *vs.* 8,804 and 818 in 2018; -0.9% and -8.6%, respectively). Among the countries that reported goat ET data in 2018 and 2019, the number of IVD embryos increased in Spain (+320.9%), UK (+96.2%), and USA (+2.3%), remained stable in Canada (0.0%), and decreased in Brazil (-81.6%). Thus, it`s unclear whether the fall in numbers is a trend or simply reflects the lower number of countries reporting data. As observed in 2018, the USA reported most of the IVD embryos (7,714; 88.4% of total), and all IVP embryos (748; 100.0%) were from Spain.

Table 12. Horses: *in vivo* derived [IVD] and *in vitro* produced [IVP] embryo collections and transfers

Region/ Country	IVD Embryos					IVP embryos					
	Flushes	Embryos	Embryo transfer			Donors	Oocytes	Embryos	Embryo transfer		
			Fresh	Frozen					Fresh	Frozen	
				Domestic	Foreign					Domestic	Foreign
Europe											
France	1,543	783	939	0	0	0	0	0	0	12	0
Italy	298	212	212	0	0	2,045	25,917	3,711	48	501	0
Russian Fed.	33	22	5	0	0	0	0	0	0	0	0
Spain	9	7	7	0	0	0	0	0	0	0	0
Sweden	34	20	20	0	0	0	0	0	0	0	0
Switzerland	0	0	0	0	0	49	236	11	0	0	0
Total	1,917	1,044	1,183	0	0	2,094	26,153	3,722	48	513	0
N America											
Canada	13	4	4	0	0	0	0	0	0	0	0
Mexico	65	58	58	0	0	0	0	0	0	0	0
USA	2,597	1,603	2,863	181	0	0	5,460	1,015	1,139	419	0
Total	2,675	1,665	2,925	181	0	0	5,460	1,015	1,139	419	0
S America											
Argentina	313	229	229	0	0	0	0	0	0	0	0
Brazil	32,640	19,260	19,028	0	0	1,563	7,716	1,566	1,147	298	0
Total	32,953	19,489	19,257	0	0	1,563	7,716	1,566	1,147	298	0
Grand Total	**37,545**	**22,198**	**23,365**	**181**	**0**	**3,657**	**39,329**	**6,303**	**2,334**	**1,230**	**0**

The horse embryo industry in 2019 was also characterized by a reduction in the number of countries reporting data (11 *vs.* 15 in 2018), but by an increase in the number of IVD and IVP embryos (22,198 *vs.* 21,312 [+4.2%] and 6,303 *vs.* 2,453 [+157.0%], respectively). The remarkable increase in the number of IVP embryos was driven mainly by Italy (3,711 [+159.3%]), USA (1,015 [0 in 2018]) and Brazil (1,566 [+352.6%]). Most of the IVD embryos were transferred fresh (99.2%). Interestingly, in spite of an increase in the total number of transfers (+4.7%), the number of frozen-thawed IVD embryos transferred decreased (-70.0%). On the other hand, more frozen-thawed IVP embryos were transferred in 2019 (1,230 *vs.* 649 in 2018 [+89.5%]). On average, 0.6 IVD embryos were collected per flush, while 10.8 oocytes were recovered per OPU session.

Thanks to the Canadian Teams, in 2019 a record of 3,959 IVD embryos were reported in cervids, and from five other countries, contrasting to the 38 embryos from Argentina reported in 2018. Also, 363 swine IVD embryos were collected in Canada, exported frozen, and transferred in the Philippines. As for 2018, ET activity in buffalo was reported by Romania and Italy only.

Table 13. Other species: *in vivo* derived [IVD] and *in vitro* produced [IVP] embryo collections and transfers

Region/ Country	IVD Embryos					IVP embryos					
	Flushes	Embryos	Embryo transfer			Donors	Oocytes	Embryos	Embryo transfer		
			Fresh	Frozen					Fresh	Frozen	
				Domestic	Foreign					Domestic	Foreign
Cervids											
Canada	0	0	0	0	111	0	0	0	0	0	0
Mexico	20	80	80	0	0	0	0	0	0	0	0
New Zealand	267	1,871	1,244	627	0	0	0	0	0	0	0
Spain	45	300	300	0	0	0	0	0	0	0	0
USA	389	1,708	779	237	0	0	0	0	0	0	0
Total	**721**	**3,959**	**2,403**	**864**	**111**	**0**	**0**	**0**	**0**	**0**	**0**
Swine											
Canada	25	363	0	0	0	0	0	0	0	0	0
Philippines	0	0	0	0	363	0	0	0	0	0	0
Total	**25**	**363**	**0**	**0**	**363**	**0**	**0**	**0**	**0**	**0**	**0**
Buffalo											
Italy	0	0	0	19	0	0	0	0	0	0	0
Romania	5	6	6	0	0	0	0	0	0	0	0
Total	**5**	**6**	**6**	**19**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

4.1.4 Exports

Table 14. Countries exporting embryos

Region/ Country	Bovine				Sheep	Goat	Horse	Swine
	IVD		IVP		IVD	IVD	IVP	IVD
	Dairy	Beef	OPU	Abattoir				
Europe								
Austria	58	0	0	0	0	0	0	0
Belgium	6	76	0	0	0	0	0	0
Finland	611	0	353	0	0	0	0	0
France	208	219	126	0	0	0	0	0
Germany	132	0	0	0	0	0	0	0
Norway	0	41	0	0	0	0	0	0
Spain	0	70	0	0	350	0	0	0
Switzerland	51	0	0	0	0	0	1	0
Total	1,066	406	479	0	350	0	1	0
N America								
Canada	3,699	3,469	1,305	0	77	6	0	363
United States	14,033	3,212	6,474	0	0	0	0	0
Total	17,732	6,681	7,779	0	77	6	0	363
S America								
Argentina	0	2,458	1,156	0	0	0	0	0
Brazil	0	0	1,229	0	0	0	0	0
Total	0	2,458	2,385	0	0	0	0	0
Grand Total	**18,798**	**9,545**	**10,643**	**0**	**427**	**6**	**1**	**363**

The number of embryos exported is shown in Table 14. A greater number of bovine embryos were exported in 2019, compared with 2018 (38,986 *vs.* 32,648, respectively [+19.4%]), with an increase of 6.5% for IVD and of 73.5% for IVP embryos. Moreover, the export of embryos was also reported in sheep, goats, horses, and pigs. Exported bovine IVD embryos were predominantly from dairy breeds (66.3%) and all exported cattle IVP embryos were produced with oocytes recovered by OPU.

4.2 Historical series and trends

The historical series of cattle embryo production (IVD, IVP, and total) in the past 20 years (2000 to 2019) is shown in Figure 2. The development of IVEP contributed to most of the increase in the total numbers, as the number of IVD embryos follows a trend of reduction since 2005. This year, the minor increase in the number of IVP embryos was not enough to counterbalance the decrease observed for IVD embryos, resulting in the first reduction in totals since 2014. The number of IVP and IVD embryos recorded per region are shown in Figures 3 and 4, respectively. For over a decade, South America (particularly Brazil) was responsible for the significant increase in IVP numbers. However, the rapid growth of IVEP in North America in the past five years changed this scenario, eventually overtaking South America numbers and pushing the world embryo totals to over 1.4 million embryos reported per year. The proportion of frozen-thawed IVD and IVP embryos transferred from 2000 to 2019 is shown in Figure 4. As IVEP increased in the early 2000', there was a parallel increase in the proportion of frozen IVD embryos, stabilizing at circa 60%. On the other hand, the use of frozen IVP embryos decreased until 2010, but has increased consistently since then, reaching over 40% in 2019.

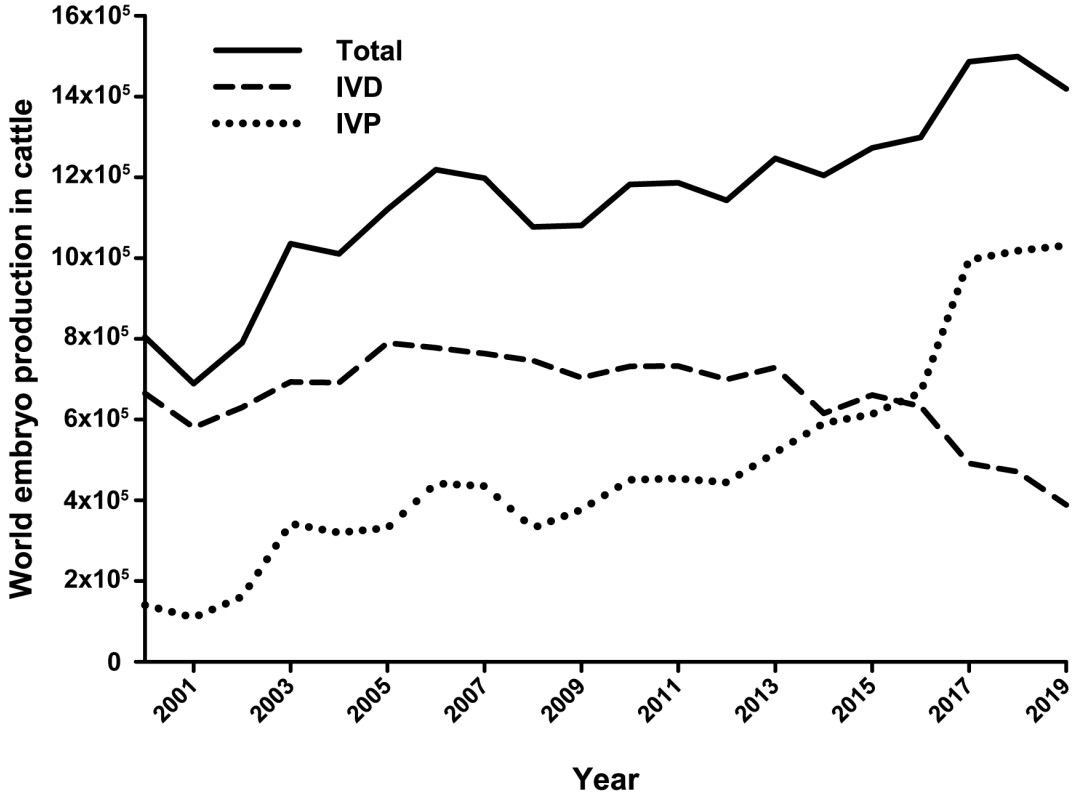

Figure 2. Number of bovine embryos (*in vivo* derived [IVD], *in vitro* produced [IVP], and total) recorded in the period 2000-2019

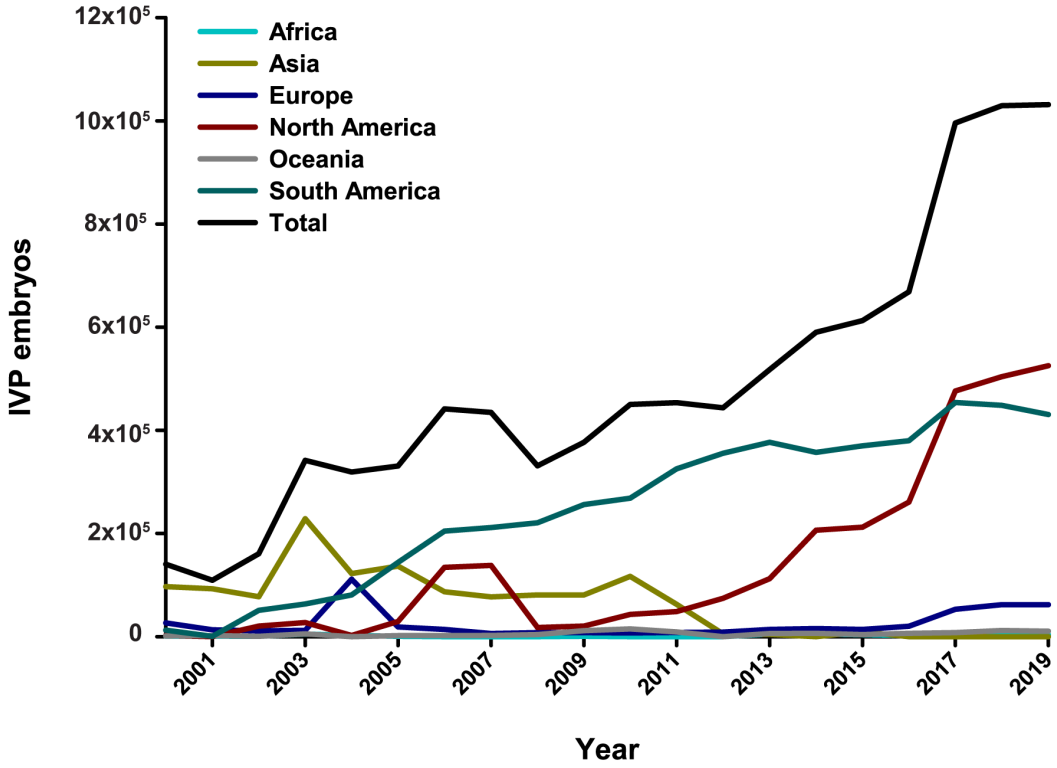

Figure 3. Number of *in vitro* produced [IVP] bovine embryos in the period of 2000-2019, by continent

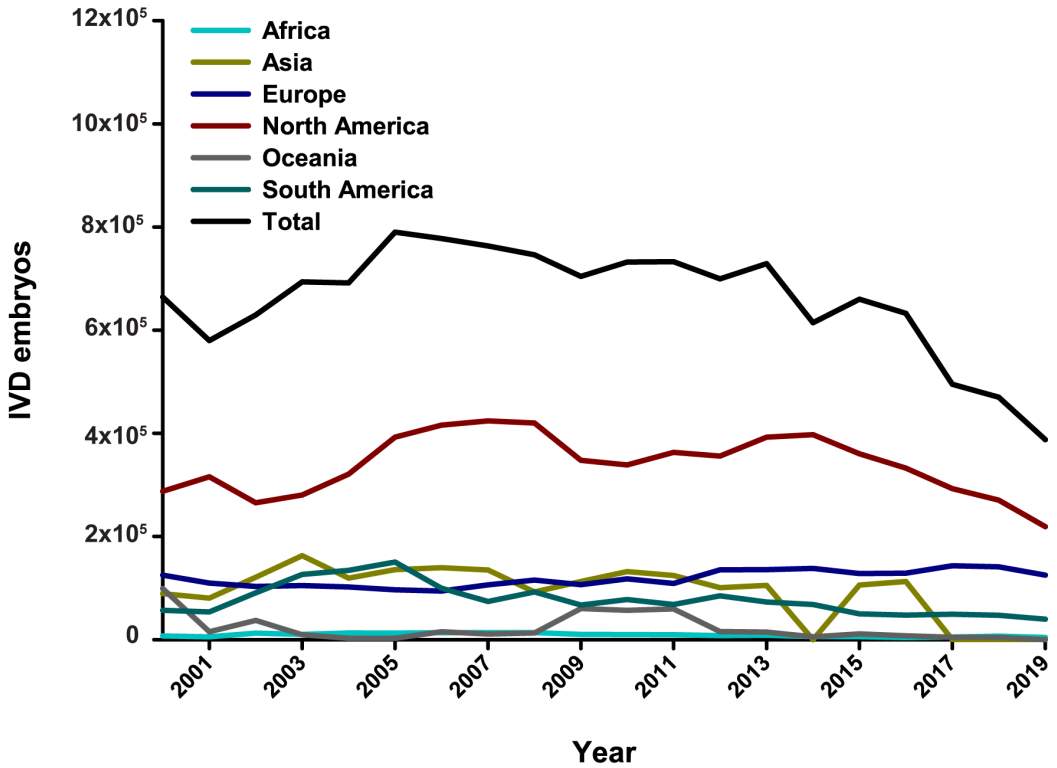

Figure 4. Number of *in vivo* derived [IVD] bovine embryos in the period of 2000-2019, by continent

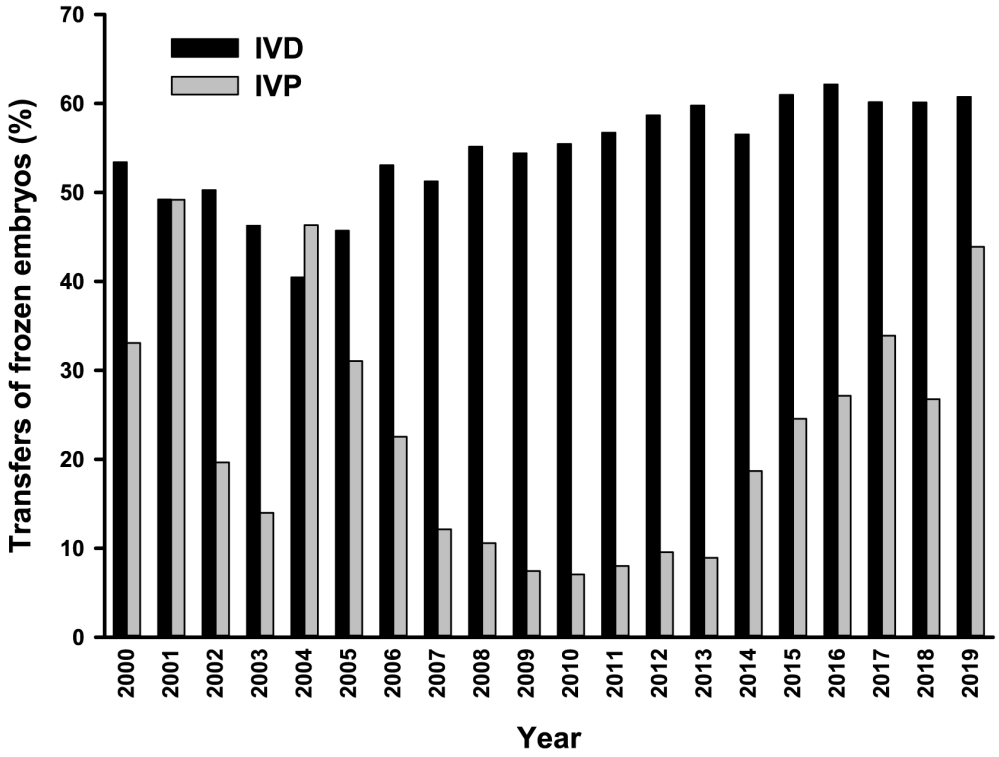

Figure 5. Proportion of transfers of frozen bovine embryos in the period of 2000-2019, according to the origin of the embryo (*in vivo* derived [IVD] or *in vitro* produced [IVP])

5. Discussion

The year 2019 consolidated trends of the world embryo industry observed in the past few years (Viana, 2019). The number of IVP embryos in cattle remained above one million records, accounting for 72.7% of all bovine embryos reported. IVP also increased in sheep and horses. It is noticeable that the main figures of the embryo industry in 2019 were not shaped by features of ET activity from a particular country or region, as occurred frequently in the past (e.g., see IVP numbers in the early 2000s' in Figure 3). Instead, fluctuations such as the decrease in the numbers of IVD embryos (Figure 4) and the increase in the percentage of IVP embryos actually transferred or in transfers of frozen-thawed embryos were observed in all regions, i.e., were global tendencies. The convergent trends worldwide facilitate the interpretation of data and the projection of future developments for the embryo industry. Moreover, it makes data analysis less prone to bias due to underreporting, which is still a problem in regions such as Oceania and Asia.

The increasing adoption and the characteristics of IVEP may explain this phenomenon. Differently from *in vivo* embryo collection, performed mostly by small, local ET teams (and thus more affected by local conditions), IVEP has led to the emergence of large, multinational companies. These companies are likely to adopt similar procedures and market strategies in different countries, and thus to reduce regional differences in tendencies - a "globalization" of ET activity. Conversely, although IVEP in other species has followed the trends in cattle and increased substantially over the past few years (+1,622.7% in sheep, +376.8% in goats, and +1,126.2% in horses from 2017 to 2019), reports are still restricted to a few countries, resulting in substantial differences among regions.

The decrease in the total bovine embryos reported in 2019 could point out to a retraction in global ET activity, characterized by the stabilization of IVEP activity and by a

decrease in the number of superovulations and flushes. In fact, the number of IVD embryos has followed a trend of reduction since 2005, which have accelerated after 2014. A faster decline in IVD numbers were initially attributed to the lack of Japanese data in 2017 (Viana, 2018), as in 2016 Japan accounted for 17.8% of world IVD numbers. However, this country has not reported ET data thereafter, while the rate of reduction increased from -4.2% in 2018 to -17.5% in 2019. Until 2018, the decline in the numbers of IVD embryos was compensated by the rise of IVEP, initially in South and later in North America, resulting in a positive balance in total embryo records – a fact that did not occur in 2019.

Interestingly, despite the relative stabilization of IVEP, the number of transfers of IVP embryos increased 7.3% in 2019, counterbalancing the reduction in IVD embryos (-17.1%) and leading to a reduction of only 1.1% in the total transfers (IVD+IVP), when compared with 2018. This difference is explained by an increase in the proportion of IVP embryos that were actually transferred, indicating that less embryos were discarded or lost, and ultimately demonstrating that IVEP is becoming more efficient over the years. The parallel increase in the proportion of frozen IVP embryos also suggests improvements in the *in vitro* culture systems, as the success of cryopreservation is directly dependent on embryo quality. Altogether, these observations demonstrate that changes in IVEP efficiency, rather than in the total embryo production, are driving the current figures of the ET industry. A contrasting scenario is seen for IVD embryos, where no significant change was observed in the past decade in indexes such as viable embryos collected per flush, or proportion of frozen embryos (6.4 and 60.8% *vs.* 7.0 and 55.5% in 2010 [Stroud, 2011]). These differences in the development of the technologies may explain the divergent trends currently observed for IVD and IVP embryos. Additionally, 27.3% of all bovine embryos exported in 2019 were IVP. As IVEP replaces superovulation as the technique of choice for the production of embryos worldwide, it is likely that the demand for the international trade of IVP embryos continue to grow – and push the standards of embryo quality and the demand for the use of cryopreservation.

6. Acknowledgements

The Data Retrieval Committee thank the efforts of all regional data collectors, as well as all practitioners or representatives of ET companies who reported data to the database or directly to the Chair. The comprehensiveness of the present report is the result of the volunteer collaboration of all these colleagues. The Chair also thank Dr. Luiz Siqueira for reviewing this report.

7. References

Stroud, B. The year 2010 worldwide statistics of embryo transfer in domestic farm animals. Embryo Transfer Newsl, v.29(4), p.14-23, 2011.

Viana JHM. 2017 Statistics of embryo production and transfer in domestic farm animals: Is it a turning point? In 2017 more *in vitro*-produced than *in vivo*-derived embryos were transferred worldwide. Embryo Transfer Newsl, v.36(4), p.8-25, 2018.

Viana JHM. 2018 Statistics of embryo production and transfer in domestic farm animals. Embryo production on a new level: over one million embryos produced *in vitro*. Embryo Transfer Newsl, v.37(4), p.7-25, 2019.

Appendix 1: National data collectors in 2019

Region/Country	Collector	Region/Country	Collector
Africa		**Europe**	
Rep South Africa	Morne de la Rey	AETE	Héléne Quinton
		Austria	Friedrich Führer
Asia		Belgium	Peter Vercauteren, Isabelle Donnay
Israel	Amir Shifman, Yoel Zeron	Denmark	Henrik Callesen
Philippines	Reuben Mapletoft (CETA)	Finland	Seija Vahtiala
		France	Serge Lacaze
Central America		Germany	Hubert Cramer
Panama	Luis Nasser	Greece	Foteini Samartzi
		Ireland	Patrick Lonergan
North America		Italy	Giovanna Lazzari
Canada	Reuben Mapletoft (CETA)	Latvia	Vita Antane
Mexico	Salvador Romo, IVB	Lithuania	Raisa Nainiene
United States	Daniela Demetrio (AETA)	The Netherlands	Helga Flapper, Hilde Aardema
		Norway	Marja Mikkola
South America		Portugal	João Nestor Chagas e Silva
Argentina (bovine)	Gabriel Bo	Romania	Stefan Ciornei
Argentina (equine)	Fernando Riera	Russian Federation	Denis Knurow, Viktor Madison, IVB
Brazil (bovine)	Joao Viana	Serbia	Aleksandar Milovanovic
Brazil (equine)	Marco Alvarenga	Slovenia	Janko Mrkun
Brazil (small rum)	Joanna Souza-Fafjan	Spain	Daniel Martinez Bello, CETA
Bolivia	IVB / Joao Viana *	Sweden	Renée Båge
Colombia	Jorge Zambrano Varon	Switzerland	Rainer Saner
Paraguay	María Benítez Mora, Gabriel Soria	United Kingdom	Roger Sturmey, Brian Graham, CETA
Peru	Edwin Mellisho		
Uruguay	IVB / Joao Viana *		
Venezuela	IVB / Joao Viana *		
Oceania			
Australia	Cedric M Wise, Genstock WA, IVB		
News Zealand	Reuben Mapletoft (CETA)		

* Data collected/organized by the Chair