REDES- Revista hispana para el análisis de redes sociales
Vol.21,#7, Diciembre 2011
http://revista-redes.rediris.es

Training links and transmission of knowledge in 18th Century botany: a social network analysis

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Abstract

This contribution develops a social network approach to the training of European botanists in the 18th century. In a period when the study of plants increasingly became an autonomous field of research, the practice of botany and related sciences mobilized a very diverse group of actors. For many of them, initiation to the science of plants was part of their medical studies. Others were trained as collaborators with an outstanding scholar in the context of a royal garden or elsewhere, sometimes also in philosophy colleges or faculties. Still others were self-taught. To the extent that biographical data were available, we made a systematic census of the masters and disciples of a set of 928 Western botanists active between 1700 and 1830. Three subsets were thus identified, each of them showing distinct characteristics and developmental patterns. The specific features of these subsets are discussed in a historical perspective, with a particular attention to the various institutional contexts which produced them. The data analysis basically shows the growing autonomy of botany with regard to medical training, as well as the increasingly national character of the dominant schools, at least in France.

Key words: history of botany - 18th century - training links - national schools

Resumen

En esta contribución se desarrolla un enfoque de redes sociales sobre la formación de los botánicos europeos en el siglo XVIII.

En un período en el que el estudio de las plantas se estaba convirtiendo en un campo autónomo de investigación, la práctica de la botánica y otras ciencias relacionadas movilizó a un grupo muy diverso de actores. Para muchos de ellos, la iniciación en la ciencia de las plantas fue parte de sus estudios de medicina. Otros fueron formados como colaboradores de un erudito destacado en el contexto de un jardín real, a veces también en las facultades de filosofía. Otros fueron autodidactas. Con los datos biográficos disponibles hemos realizado un censo sistemático de los maestros y discípulos de un conjunto de 928 botánicos occidentales activos entre 1700 y 1830. De este modo hemos identificado tres subgrupos, cada uno de ellos con distintas características y lógicas de desarrollo. Las características específicas de estos subgrupos se analizan desde una perspectiva histórica, con especial atención a los diversos contextos institucionales que los produjeron. El análisis de los datos muestra la creciente autonomía de la botánica respecto a la formación médica, así como el carácter cada vez más nacional de las escuelas dominantes, al menos en Francia.

Palabras clave: Historia de la botánica – Siglo XVIII – Contactos de formación – Escuelas nacionales.

[1] The authors thank the anonymous reviewers of the review REDES for their very useful critical remarks, Natalia Tikhonov Sigrist for her attempts to make their style sound a little more English and Julia Carmine for the final version of the article. Send correspondence to: sigrist.rene@bluewin.ch

1. Introduction

The use of social network analysis to develop a better understanding of research practices is now fully acknowledged in natural history (Spary, 2008). In the specific field of botany as in others, the introduction of a network perspective implies the acceptance of a conception of science as being a matter of interactions between scholars as well as a succession of theoretical paradigms. The obvious consequence is to shift the focus of historiography from the traditional investigations into ideas, theories and discoveries to the analysis of the social organization of research. In the case of botany, this means that epistolary exchanges, transfers of specimens and other social intercourses have suddenly come to the forefront (Dauser & al., 2008). Beyond the study of ego-networks, attempts have been made to develop a visual representation of academic affiliations (Stuber, Haechler, Krempel & Ruisinger, 2008), to follow the making of a set of standard botanical illustrations (Nickelsen, 2008) or to describe a local system of plant transfer (Stuber, 2008). Yet, no global study of the European field of botany has been sketched out so far. The present article aims at introducing such a perspective for the period 1670 to 1830, when the organization of science was dominated by a few royal academies. Through the analytical description of training links between masters and disciples, its purpose is to characterize the main channels leading to the emerging field of botany.

Before the professional scientist became a dominant norm in the second half of the 19th century, members of the "Republic of Science" were of various social and cultural backgrounds. The making of a scientific field, either specialized or not, required that involved actors share some common ideals and norms, and be able to cooperate in an efficient way. As for any other kind of collective investigations, the study of plants generated various types of links between participants. Among botanists, the most ordinary interaction took the form of exchanges of letters and specimens. Intellectual influences can be considered as another type of link, even though the tracks they left were less obvious than in the case of editions or translations of peers' works. Personal visits, joint trips and publications established more direct connections. From a social network point of view, these closer forms of collaborations established a kind of backbone of the "Republic of Botanists", where exchanges of information and materials defined its ordinary way of functioning. The frontiers of this social and intellectual field were obviously uncertain and movable. Yet, access to its tiny hard core of full professionals who enjoyed paid positions was regulated through a combination of training, patronage and sometimes family links. The present article focuses on the training links between masters and disciples, established between

botanists and through socialization to the principles of their science was passed along.

Being that the final aim of science is the establishment of universal truths about nature, it is often assumed that location does not affect its conduct and neither does the status of its various actors matter. Since the ideal of the Republic of Letters emerged in Renaissance Europe, the development of scholarship has always been conceived as requiring a universal space of collaboration between scholars of all origins, social status and denominations (Bots & Waquet, 1997). Before the triumph of positivism, philosophers and scholars of the Enlightenment had proclaimed the universal character of scientific practice as a precondition of its objectivity. Even among historians, for a long time the dominant view remained that valuable scientific knowledge was untouched by social, cultural and local conditions. Enlightenment science in particular is still considered immune from the poison of scientific nationalism which contaminated the 19th and 20th centuries. However we have previously shown that in the 18th century the great monarchies competed for the dominance over the "Empire of Science" as they disputed for the Empire of the Seas (Sigrist, 2008a). Scientists were themselves confronted by certain geographical limits in their significant exchanges of correspondence (Sigrist, 2008b; Sigrist 2009). It is therefore to be expected, even if it goes against the grain, that Enlightenment botany had its own proper geography.

The notion of training links and the national origins of scholars

The master-disciple relationship is of crucial importance to the transmission of knowledge and to its further development. For the younger generation it involves an initiation to a kind of specialized scholarship, and ensures for the older generation the diffusion of its tenets and the continuity of its fame. It is therefore not a fully one-sided relation, since it conveys a certain degree of *interdependency* between masters and disciples. It is often associated with other kinds of links, such as intellectual influence, patronage, collaboration and in a few cases family links. Intellectual influences, which are the most likely to be confused with training links, do not require any direct personal relation, but only a recognized debt to the theoretical or methodological importance of another scholar. For a botanist, such intellectual influence would for instance be established by the use of a system of classification devised by another scholar.

The master-disciple relationship, or training link, is a locally determined personal relation between two individuals, one providing a formal teaching to the other, either in a university context or not. When the master is also the doctoral supervisor of the

student, or when the doctoral student also works as a laboratory assistant to his master, the link has double or even three-fold intensity. Such kinds of links are established when mentioned in a printed biography of either disciple or master, notably among those collected in the *World Biographical Information System* (WBIS). It is of course highly dependent on the actual state of historiography, since no comprehensive survey of primary documents (university registers for instance) is possible on such a large scale.

Given the diversity of actors of the "Republic of Botanists" and the great variety of their locations, origins and social status, the links they developed over years of training or later in their careers played a crucial role in the making of a scientific field devoted to botany. At a local level, this field was mainly made of family ties and patronages. At a global level, they were made of intellectual or material exchanges and influences. And somewhere in-between existed the various forms of cooperation (joint publications or travels, common investigations). As for the training links, their exact scope remains to be determined, as well does the role they played in the development of an international community of botanists.

Finding out whether master disciple relationships had a mainly international, national or local nature, requires a sense of the geographical mobility of students in botany, and therefore to identify their national origins. Since the cultural significance of borders, and in some cases even their political meaning, were far from clear in the 18th century, some precisions are necessary about the way these territorial entities have been defined for the present investigation. As a matter of fact, some important nations, such as Germany or Italy, were divided between various states. The loosely defined Holy Empire included real powers (Prussia, Bavaria, Saxony, Austria) as well as tiny local sovereignties of uncertain status. Nuclei of smaller nations (Czechs) were also included in the Holy Empire, until they joined the Hungarians and other nationals within the Austrian empire (formally proclaimed in 1806). The same situation occurred to the Baltic groups within the Russian Empire, the Finns within the Swedish Empire, the Irish within the United Kingdom, the Norwegians in Denmark and even the Poles after the successive partitions of their country. Yet, in each case, no simple criterion can be used to determine which persons belonged to which ethnic groups. An additional difficulty comes from the changing configuration of frontiers, especially between 1792 and 1815. Therefore, an investigation about geographical mobility can hardly be based on nations as we conceive them now or on states as they existed in the 18th century. Since the question here is about spatial localisation and spatial mobility of students and not about their national or imperial

feelings or identification, it may suffice to consider geographical entities which have a cultural or territorial significance, whatever their political nature (nation, empire, federal state or colony) may be. The term "national" will be used throughout this paper as a short cut to refer to these entities, which had a territorial or cultural significance in 18th Europe. A botanist's nationality is determined according to his origins. Considering multiple nationalities according to the places of activity makes for few changes, except for Russia, which imported many scholars, and perhaps for Switzerland, which exported many.

About 74% of the botanists that we are going to consider come from four territorial entities of national character: France, Great Britain (Ireland included), "Germany" (that is all the German speaking territories of the Holy Empire, with the exception of the Habsburg dominions) and "Italy" (which includes all the Italian speaking states). The remaining 25% of botanists mainly belonged to nine further entities: Sweden (including Finland), the Netherlands, Switzerland, the Russian Empire, the Austrian Empire, the United States (British colony until 1776), Denmark (including Norway), Spain and Portugal. Only 1 or 2% came from further European territories (Poland, Belgium) or from colonies (Mexico, Colombia, South Africa).

Previous investigations (Sigrist, 2008b and 2009) have shown that in the 18th century, a large majority of significant epistolary exchanges occurred between scholars speaking the same vernacular language or belonging to the same territorial or cultural entity, especially for the major groups (France, Great-Britain, "Germany", "Italy"). This fact has probably been hidden so far by the international character and extent of the ego-networks of a handful of prominent botanists such as Carl von Linné, Albrecht von Haller or Joseph Banks. Despite these national limitations, chains of epistolary exchanges allowed news to travel rather efficiently from the main centres of the Republic of Letters to its remotest parts, whereas translations and intellectual influences easily skipped national or linguistic borders. In the case of botanical training, the use of Latin remains the rule, except for France, so that we do not expect linguistic borders to limit students' migrations.

Defining a sample of 18th century botanists

Defining botanists as men of science who have received a formal training in botany would probably be an over-simplification of 18th century realities. Even though contemporaries had few opportunities to perceive the botanists as a separate group of scholars, none of them would probably have limited a possible inventory to the only scholars with a high school curriculum. Carl von Linné, who attempted to establish a detailed taxonomy of botanists in his *Philosophia botanica* (1751), did not

separate academic specialists from non-academics. His aim was indeed more prescriptive than descriptive, since he just wanted to define a new discipline and its practitioners in a way that would express his own taxonomic ideals (Müller-Wille, 1999). Linné cared little about historical realities and the notion of *Respublica botanici* ("Republic of botanists") he used in his correspondence with Albrecht von Haller (1737)[2] met little success. The identity of botanists as a separate group of scholars remained in fact uncertain until the early 18th century and perhaps as far as 1750. Practicing a science did not mean being a recognized specialist of it, much less being a professional practitioner, and this statement is as true for botanists as it is for instance for chemists (Hannaway, 1975). A distinction has therefore to be made between the emergence of botany as a science and its identification as a social practice.

Linné himself considered that botany began in the early 16th century with the ability to establish a *diagnosis*, that is to identify the true nature of a plant. Of course, plants have been studied much earlier, and Linné mentions quite a few "fathers of botany" up to the famous Theophrastus, Pliny and Dioscorides in Antiquity or belonging to the Latin and Arabic Middle Ages. Yet, their inability to establish *diagnosis* did not entitle them to be considered as true botanists. As for *modern* botany, it started, according to Linné, with the use of the sexual system of plants made possible by the discoveries of the sexual character of plants by Camerarius (1694) and above all by Sébastien Vaillant (1717). Linné's own use of the sexuality of plants to establish a new system of plant classification started in 1737. Now, if botany was established since the Renaissance as a category used to classify a genre of books in libraries or to define a subject of university teaching, what about the botanists? The creation, by the 1540s, of the first university gardens did not imply a clear distinction between the botanist, who had to supervise the garden, and the professor of medicine, who taught *materia medica* (pharmacology) as part of his academic duties. Indeed, both functions were usually united in a single person. The first paid botanists appeared in the mid-to-late 17th century, either as members of a royal academy of as travelling naturalists sponsored by the king. The word "botanist" probably dates from this period, but in comparison to the term "botany" its use remained scarce until the middle of the 18th century (**Table 1**). Thus it is logical to conclude that despite the existence of a few professional botanists since the end of

[2] The Linnaean Correspondence, an electronic edition prepared by Eva Nyström and the Swedish Linnaeus Society, Uppsala, and published by the Centre international d'étude du XVIIIe siècle, Ferney-Voltaire. The letter to Haller is dated June 8th 1737.

the 17th century, their recognition as a specialized group of scholars by society at large did not happen before the 1750s or even the 1780s. It should be noted that by the middle of the 18th century botanists also began to argue about the frontiers of their discipline (Bungener, 2007).

Year	English	French	German
1700-1750	3%	2 %	2 %
1751-1780	5%	12	13
1781-1800	11%	31	59
1801-1810	27%	41	48
1811-1820	29%	45	49
1821-1830	27%	44	36

Table 1: Ratio of use of the word "botanist" compared to the word "botany" in the 18th century (Inquiry conducted in January 2010 on the basis of texts in English, in French and German available on http://books.google.com). Despite linguistic constraints and significant differences between idioms, it clearly appears that until 1780, the specialists of botany were less clearly perceived by European societies than the science of plants itself. As for the word "botany", it appeared in the 17th century, whereas the French word "botanique" already existed in the 16th century.

With the hindsight historians are probably in a better position than their contemporaries to identify scholars who practiced botanical science. But which criteria should be considered crucial? Linné himself made a distinction between dozens of different tasks, each supposed to be performed by a specific kind of actors (Sigrist, 2011a). Leading botanists were certainly able to combine many of these tasks, if not all of them, while others, especially those considered by Linné as mere "botanophiles", only performed one or two. Publication was not always part of them and recent attempt to propose a categorization of botanists (Steinke, 2008; Haechler, 2008) do not consider it as a crucial factor.

The Republic of Botanists has certainly included various kinds of actors whose common feature was collaboration in the study of plants, and notably the practice of material and scholarly exchanges. For a small elite, social identification as practicing botanists was eased by their affiliations to academies or their formal positions within botanical gardens, universities or other teaching institutions. The simple criterion of academic affiliation to one of the six major academies of the period 1700-1830 (Paris, London, Berlin, St-Petersburg, Stockholm, Bologna) allows for identification of a first corpus of 301 specialized botanists. When significant publications become a criterion, justifying a presence in Robert M. Gascoigne's *Historical Catalogue of Scientists* (1984), it allows extention of this corpus of specialized botanists to 743 individuals. This set can be extended in two further directions:

1°. By considering various categories of minor botanists, starting with those included in R. K. Brummitt & C. E. Powell's, *Authors of plant names* (1992), in Frans A. Stafleu & Richard S. Cowan's *Taxonomic Literature* (1976-1988), and further registering amateurs whose activities have left some tracks at a local level.

2°. By registering unspecialized botanists, practising the science of plants besides natural history or medicine, even on an occasional basis. Beyond the true botanists specialized in taxonomy, plant anatomy and botanical medicine, it is also possible to consider vegetable physiologists (or physicists), agronomists, gardeners, nurserymen and forestry engineers as other categories of unspecialized botanists.

To put some systematic order in these uncertain categories, one can consider botanists according to fame and to degree of involvement in the discipline. Obviously, the two aspects are more or less correlated, but this should not prevent us from using them to classify participants in the botanical enterprise, nor to introduce subcategories for statistical purposes.

As for the supposed importance of their scientific contribution or their status within the scientific community, one can make a distinction between: A. major scholars; B. second-rank scholars; C. amateurs. As to their degree of participation in the study of plants, these scholars fall in the following categories: 1. specialized botanists; 2. non-specialized botanists; 3. occasional botanists. By combining both sets of criteria, it becomes theoretically possible to define no less than 9 formal categories of actors, headed by the major specialized botanist (A1) and the second-rank specialized botanist (B1) (**Table 2**). They are followed by less prestigious groups of unspecialized scholars of major or minor importance (A2, B2) and by further minor and less implicated categories of actors (C1, C2, A3, B3), down to the evanescent occasional amateurs of botany (C3). Defined this way, the 18th century Republic of botanists may have involved, at various degrees, tens of thousands actors across the Western world. Among them, only a few hundred belonged to the major categories which played a significant role in the establishment of the discipline.

	A. Major scholars	**B. Second-rank scholars**	**C. Minor scholars and amateurs**
1. Specialized botanists	**165** identified (100 %)	**574** identified (100 %)	c. 1100 "botanophiles"
2. Non-specialized botanists	**71** identified (c. 25 %)	**118** identified (c. 12-15 %)	"herbalists"
3. Occasional botanists	a few identified (Buffon, Laxman)	a few identified (Rousseau, Karpinski)	"dilettanti"

Table 2. Formal categorization and estimated number of persons involved in botany between 1700 and 1830.

The use of formal criteria of identification allows determining the members of these different categories of actors.

A. **Major scholars** are identified by their affiliations (as members, fellows or correspondents) to at least two of the six major academies of the time or by their inclusion in the *Dictionary of Scientific Biography* (DSB). Among the 1'640 scholars of this kind active between 1700 and 1825, 165 can be identified as specialized botanists (A1), having botany as their main field of research. At least 71 further scholars are mentioned as non-specialised botanists (A2) by the DSB or by academic records: they have indeed practiced botany as a subsidiary field of research or were specialists of neighbouring fields such as agronomy or vegetable physiology. But on the basis of a monographic study of scholars active in Russia (Elina, 2008), one can guess that the total number of those who made some botanical investigations under the cover of medicine, natural history, pharmacy or even chemistry is probably four times higher. The category of major scholars further includes an undetermined number of individuals who practiced botany only occasionally (A3). Some of them can be identified, like the Finnish priest and geologist Eric Laxman or the famous Buffon, who headed the Jardin du Roi in Paris for 49 years without botanizing a single time !

B. The category of **second-rank scholars** includes all the other persons affiliated to one of the six majors academies of the 18th century, or registered in Robert M. Gascoigne's *Historical Catalogue of Scientists and Scientific Books* (1984). Among the 4'248 scholars of this kind active between 1700 and 1825, 574 can be identified as specialized botanists (B1), but many more practiced botany on a less regular basis, either as a secondary "discipline" (B2) or as an occasional activity (B3). The

group B2 includes a majority of physicians whereas the group B3 of leisure-time botanists is made of scholars specialized in diverse fields of research, including men of letters and philosophers such as Jean-Jacques Rousseau.

C. Finally, a third category of **minor scholars and amateurs** (C) can be defined as those who practiced botany in a less intense or less successful way. At a local level, they can be identified on the basis of: publications (at least one); institutional positions (such as professors of botany, directors of botanical gardens and keepers of herbaria); cooperation with first-rank botanists; membership of a botanical society; ownership of a botanical garden or a herbarium. The most persevering ones (C1) can be associated with Linné's "botanophiles". On the basis of local investigations made in Geneva, St-Petersburg, Göttingen and Florence, their total number can be judged as being about 1,5 times the number of specialists of categories A1 and B1 taken together. Another category, labelled as "herbalists" (C2), can be defined as a group of collectors of medicinal plants which would include many pharmacists, priests and member of urban and rural classes, with a significant proportion of women. Finally, the category of "dilettanti" (C3) would include occasional amateurs of the cultivated middle and upper classes ("Bildungsbürtergum"), with a significant proportion (perhaps even a majority) of women. Like Mme Gautier Delessert, the recipient of Rousseau's letters on botany, in addition to the Empress Josephine, they ensured the diffusion of books on flowers and gardening and made the core audience of many botanical courses. One of the characteristic features of the 18th century, especially in its latest phase, is precisely the explosive growth of minor botanists and amateurs of all kinds.

For reasons of availability of biographical data, this contribution focuses on an elite of botanists limited to 928 more or less involved scholars (see again Table 2). This set is made for 80% of specialists of the groups A1 and B1, and for 20% of less-specialized botanists belonging to A2 and B2. In order to include the masters of the first generation and the disciples of the last generation of our set, we decided to consider a further group of 81 scholars living before 1700 or after 1825. Among them, 28 were themselves botanists, either specialized or not.

2. The network of masters and disciples

The network analysis has been limited to an elite of 928 scholars belonging mainly to the categories of specialists of botany A1 and B1, or representative (in 20 % of the cases) of the large categories A2 and B2 of non-specialized botanists. We have considered as training links all the relations between these botanists and their masters or their disciples of any field of investigation, as long as they appear as men of science according to the criteria defining categories A or B.

Overall, the network has a very low density (one percent). This is accounted for by the following facts: 1° the training relations are strongly structured by chronological frame; 2° they only concern links between few individuals; 3° most individuals have only one adviser, whereas advisers usually have few disciples. The centralization is low as well, with outdegree centralization scoring 1,6% and betweenness centralization 0,07%. Despite these low density and very low centrality, the network shows signs of structures, with areas of higher densities separated by holes.

In order to go beyond the scarcity of ties characterizing the network, we focused on individuals who have at least one connection with others. Of the 928 botanists, 518 appear as isolates, either because they were self-trained, or because no track of formal training by another scholar A or B has been recorded so far[3]. The other 410 had at least one teacher or one disciple among scholars we identified according to criteria A or B. 81 of these related scholars lived either before 1700 or after 1830, 28 of them were botanists themselves. It is therefore possible to consider that our set of interconnected botanists equals 438 (410 + 28). 40% of them belong to the category of major scholars (category "A") and 60% to the second-rank ones (category "B").

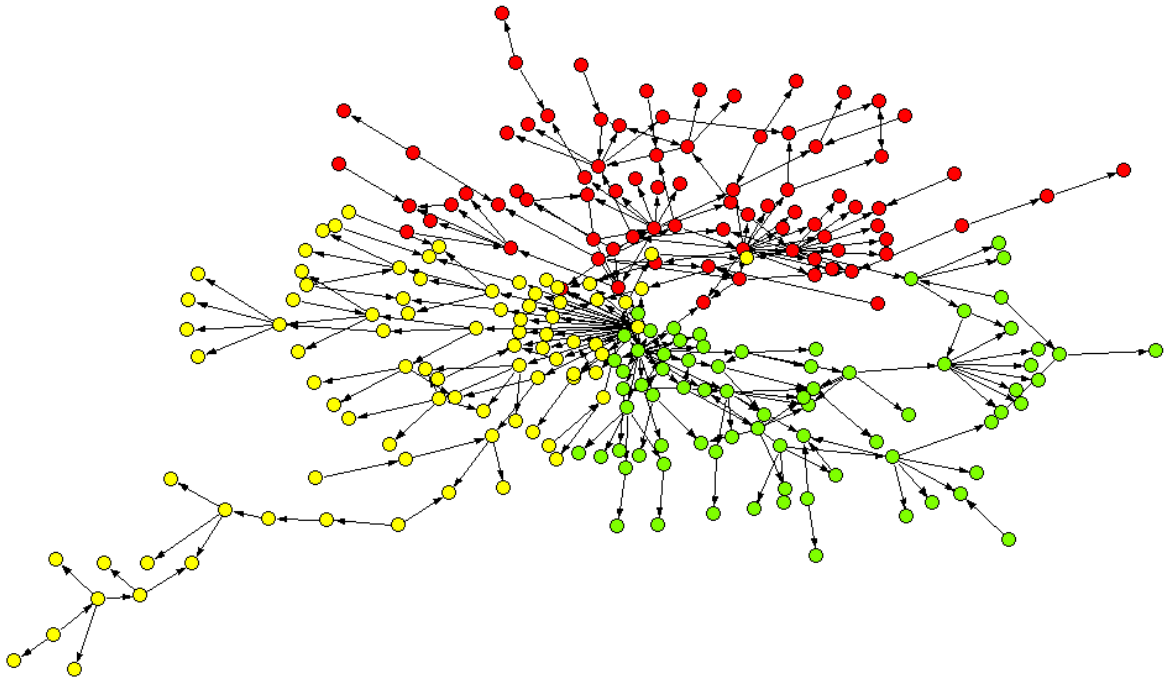
Among these connected botanists, we computed components, i.e. sub-graphs of a graph that are connected within but disconnected between sub-graphs. Components divide the network into separate parts, where each part has several actors who are connected to one another (Hannemann & Riddle, 2005). In a component every actor is indirectly or directly connected to every other actor. In substantive terms, weak components capture series of scholars who are directly or, most often, indirectly, connected with each other by pseudo-genealogical ties between masters and disciples. In other words, in a component, several genealogies of masters and

[3] We excluded many links that were only probable, or even highly probable, but not certain, as well as all the links with scholars who do not figure in our set of clearly identifiable men of science. Improved biographical data and closer investigations in university curricula would have obviously reduced the number of isolates.

disciples intersect because of common ancestors or common descent. Weak components can be seen in this context as sparse groups developing across time. Focusing on the weak components of the graph[4], we found that it split up into 66 components. The largest one includes 242 individuals and the second largest only 9. Therefore there is a great number of very small components and isolated individuals. The largest weak component is presented in **Figure 1**[5]. It is structured by chronological time, although not linearly. At the center of the graph are the most ancient scholars (from the late 17th century), whereas the margins feature scientists of the late 18th or early 19th centuries. The figure indicates that the largest weak component is organized around a center of densely connected individuals. A visual inspection shows that it spreads into three subsets, with relatively few connections among them: one appears on the top of the graph, the other on the bottom left, and the third on the bottom right. To further assess the presence of subsets in the largest weak component by analytical tools, we used the Girwan-Newman algorithm (Girwan & Newman 2002), exploring from two to ten group solutions. The solution with three groups provided the highest fit. It confirms that the main weak component is indeed divided into three distinct subsets, colored differently in the graph. All three subsets have a density of 2% whereas relations between groups have a density very close to zero.

[4] Weak components do not take into account the direction of the ties as strong components do. Identifying components enables researchers to focus on areas of connections within sparse networks.

[5] Figures were created using Pajek (Batagelj & Mrvar 1998), a software dedicated to the analysis of large networks. In the case of the training links of botanists, we use the Kamada-Kawai algorithm.

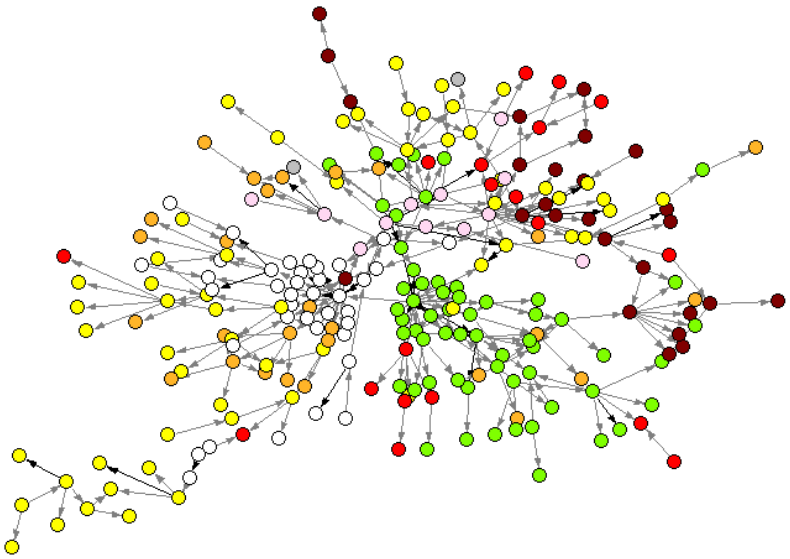


Sub Group 1- Yellow: Swedish-Germanic group	Sub Group 2- Green: French group	Sub Group 3-Red: Mixed group

Figure 1. Subsets from the Girwan-Newman algorithm applied on the largest weak component[6].

As shown by **Figure 2**, the subsets are associated with the national origins of scientists. The subset on the lower part of the graph is mostly composed of French scholars (green), with a few British (red) and Swiss botanists (brown). It is very densely connected. The group on the left stems from Swedes (white) who connect on the outer side with many Germans (yellow). These connections between Swedish and German botanists spread out in three distinct directions. The third subset, on the right side of the graph, is much more widespread and includes a mixture of Germans (yellow), Dutch (light purple) and Swiss (brown), as well as a contingent of French (green) and British scholars (red). It is therefore much more heterogeneous than the two other subsets.

[6] This graph and the following were created by the Fruchtermann-Reingold algorithm in Pajek (Batagelj & Mrvar, 1998).



Yellow: Germany	Green: France	Red: Great-Britain	Gray: Italy	White: Sweden	Brown: Switzerland	Light purple: Netherlands	Orange: Others

Figure 2. The largest weak component coloured by country of origin.

What accounts for these different subsets? **Table 3** presents various characteristics of members of the three subsets, with standard measures of association. It confirms that subsets are significantly associated with "national" origins. The first subset is mostly composed of Swedes and Germans, that the second, of 75 individuals, is mostly French and the third, of 86 individuals, is a mix of Germans, Dutch, Swiss and others.

	Swedish-Germanic sub-group (Yellow)	**French sub-group (Green)**	**Mixed sub-group (Red)**	**Chisquare (Cramer's V)**
Country of origin				216** (.67)
Germany	36	3	32	
France	0	65	12	
Great-Britain, Ireland	2	11	11	
Italy	0	0	3	
Netherlands	0	0	15	
Sweden	44	0	0	
Switzerland	1	15	17	
Other countries	16	7	10	
TOTAL	100,00%	100,00%	100,00%	
Degree of specialization				16** (18)
Botany only	71	57	53	
Botany and other science	12	17	30	
Other science and botany	11	15	16	
Other science	7	11	1	
TOTAL	100,00%	100,00%	100,00%	
Importance				7* (.17)
Scholar A	47	56	35	
Scholar B	53	44	65	
TOTAL	100,00%	100,00%	100,00%	
Year of birth (average and SD)	1757 (47)	1752 (28)	1701 (39)	51** (F-test)
Year of birth (recoded)				52** (.46)
Before 1740	35	35	84	
1740 and after	65	65	16	
TOTAL	100,00%	100,00%	100,00%	

Table 3. Characteristics of the three identified sub-groups (%).

Interestingly, various characteristics other than nationality correlate with subset membership. For instance, the members of the mixed subset are on average two generations older than those of the French and Swedish-Germanic subsets. The mixed subset is very interdisciplinary and includes less prominent scholars than the French subset. This latter subset is itself slightly more interdisciplinary and includes more famous scholars than the Swedish-Germanic subset. As for the nations, Dutch and Swedes belong to one subset only, Germans, Swiss and even French botanists belong to two distinct subsets, whereas Englishmen are scattered all over.

Figure 2 and table 3 also reveal important differences in the intensity of connections according to the nation of origin, and this feature appears the same whether one considers the whole network (N = 928 + 28), the largest weak component (N = 242), but also the smaller components and the isolated individuals. As a matter of fact, 67% of botanists born in Great-Britain are isolates, and even 90% of those born in Italy, against 40% in Sweden and 38% in Germany. The proportion of isolates is even smaller in France (24%), in the Netherlands (19%) and in Switzerland (4%). No simple explanation can be given for these differences, since the existence of many universities is not in itself a guarantee of dense training links (see Italy), whereas mediocre university systems do not exclude high levels of connections (see France and Switzerland).

Looking for the core: the bicomponent

Within the largest weak component, is there a subset of individuals especially connected and who constitute the core of the network ? In order to find this core, we decided to compute the bicomponent of the network, which is a maximal connected subset of individuals without a cut-vertex (De Nooy, Mrvar & Batagelj, 2005). In a bicomponent, no one can control the information flow between two other persons completely because there is always an alternative path that information may follow. In other words, in a bi-component each person receives information from at least two sources. In this case, the meaning of the bicomponent is slightly different, as the network has an historical depth that makes many actors unable to communicate directly with each other, since they lived in distinct times. All of them share nonetheless the basic property to be trained by at least two masters or to have at least two disciples, or to be in two paths linking a master and a disciple with other botanists. This situation is likely to be a vector of scientific influence combining continuity with change.

Seventy one scholars belong to the bicomponent, which graphically corresponds to the center of the largest weak component. **Table 4** presents various characteristics of the individuals included in the bicomponent compared with those of other members of the largest weak component and of further individuals being either isolates or belonging to smaller weak components.

	Members of the bicomponent (71)	**Other members of the largest weak component (171)**	**Isolates (714)**	**Chisquare (Cramer's V)**
Country of origin				232** (.35)
Germany	16	28	27	
France	41	18	19	
Great-Britain & Ireland	3	10	27	
Italy	0	1	10	
Netherlands	10	3	3	
Sweden	13	13	17	
Switzerland	14	9	1	
United-States	0	0	3	
Other countries	4	14	10	
Total	100,00%	100,00%	100,00%	
Degree of specialization				9 (.07)
Botany only	56	63	63	
Botany and other science	30	15	18	
Other science and botany	14	21	20	
Total	100,00%	100,00%	100,00%	
Importance				68** (.27)
Scholar A	59	40	20	
Scholar B	41	60	80	
Total	100,00%	100,00%	100,00%	
Year of birth (Mean and STD)	1720 (39)	1743 (48)	1749 (47)	12** (anova)
Yearof birth(recoded)				52** (.46)
Before 1740	66	45	36	
1740 and after	34	55	64	
Total	100,00%	100,00%	100,00%	

Table 4. Compared features (country of origin, birth period, scientific importance and degree of specialization) of the bicomponent, of the other members of the largest weak component and of the remaining botanists included in the dataset.

In the bicomponent, botanists are more often first rank ("A") scientists than in the largest weak component and in the group of other individuals. This fact is perfectly understandable if one admits that having more disciples is a means to enhance one's scientific reputation (and vice versa), and therefore to be integrated to the kernel of the emerging discipline. These individuals have also earlier birth dates than those of the two other subsets, which is a sign of greater cohesion of the group in an early period, when the major training places were limited to a few centres (Leyden, Amsterdam, Paris, Montpellier, Göttingen). The subsequent multiplication of schools in Sweden (Uppsala, Lund), Germany (Leipzig, Berlin, Karlsruhe, Halle) and elsewhere (Copenhagen, Geneva) reduced the need for botanists to practice the "*peregrinatio academica*", that is to attend courses in various foreign universities. Because botanical training was very often combined with medicine and other sciences in the early 18th century, members of the bicomponent also show somewhat more interdisciplinarity, although the difference with the other components is not great in this respect.

The bicomponent includes a much larger share of French, Dutch, Swedes and even Swiss than the largest weak component and the group of isolated individuals, and a much smaller proportion of British and Italians, as well as Germans. For the French and the Dutch, the trends observed within the largest weak component are considerably reinforced in the bicomponent, a fact that stresses the crucial role of these two nations in the teaching of botany as well as of natural and medical sciences in general (Taton, 1964; de Ridder-Symoens, 1989). The concentration of professors in Paris and in Leyden may explain this privileged position. For Sweden and Switzerland, the previously observed trends are confirmed, showing the crucial role of single individuals such as Linné, but also Haller, during his years in Göttingen. Interestingly, "Germany", which keeps its position in the weak component, recedes in the bicomponent, whereas Britain recedes even further.

3. An exploration of the three subsets

The most striking information delivered by the previous section is the existence, among the first-rank and best connected botanists of the 18th century, of subsets which indicate in the clearest possible way the existence of three distinct genealogies of botanists, with different structural characteristics. As the oldest subset includes the more internationally-trained and the less specialized individuals, our starting hypothesis of an increasingly specialized science developed in a growingly national context gains some further credit. Yet, the historical evolution of botanical training in

the 18th century was neither linear nor devoid of any paradox. To gain more information about the meaning of these three subsets, one has therefore to pay a closer attention to the composition of each of them and to record personal characteristics provided by the *World Biographical Information System*. At a second stage, we shall examine the training links within national communities of botanists that do not figure prominently in these three subsets, especially Great Britain and Italy. In these cases, biographical data will be used to establish the possible reasons of their marginal positions within the global network.

The mixed subset and its Dutch core

For the members of the mixed subset, the average birth date of 1701 indicates that the medium dates of training in botany are in the early 1720s, say around 1721. For the French subset and for the Swedish-Germanic subset, the same calculation would give 1772 and 1777 as median training dates, or a half century gap. This difference is very important to bear in mind, since the size of the international community of botanists had doubled in the meantime: the community of specialized botanists fitting our A or B criteria was 96 individuals in 1721, yet it reached the size of 180 to 190 between 1772 and 1777 (Sigrist, 2011). During the same period, the number of available institutional positions had also approximately doubled. In the next 50 years, the number of specialized botanists would double once again, reaching 370 in 1825, and the same is apparently true for the available positions.

As for the mixed subset, its institutional centre was in the Netherlands, although about one third of the botanists included in it belonged to the German countries of the Holy Empire. With 17 disciples, Hermann Boerhaave (1668-1738) appears as the most central figure of the subset (see **Figure 3**), before the Swiss German Albrecht von Haller (1708-1777) with 12 disciples and the French Joseph Pitton de Tournefort (1656-1708) with 11. Partly because of his medium chronological position between Tournefort and Haller, Hermann Boerhaave, who was professor of medicine and botany at the University of Leyden between 1709 and 1729, appears as the pivotal figure of the subset. The average date of training of the subset members coincides with the apex of his teaching of medicine, botany and chemistry at the University of Leyden[7]. Boerhaave's importance as a medical teacher was unparalleled in early 18th century Europe, so that many of his students became leading figures in either medicine or chemistry (black spots on figure 3). Some of them practiced botany

[7] Boerhaave was also professor of chemistry between 1718 and 1729, and finally professor of medicine and clinic between 1729 and 1738.

either as a major specialty (green spots) or as a subsidiary specialty (yellow spots). Among them were the Germans Heister, Trew, Boretius and Buxbaum, the Swiss Haller, Gessner, Ammann and Garcin, the British Sherard, Alston, Deering and Houstoun, the Dutch Gronovius, Burman, van Royen and de Haen and the Spaniard Ribeiro Sanches. Boerhaave's influence was further extended to Austria through de Haen and to the Russian empire through Ammann and Buxbaum.

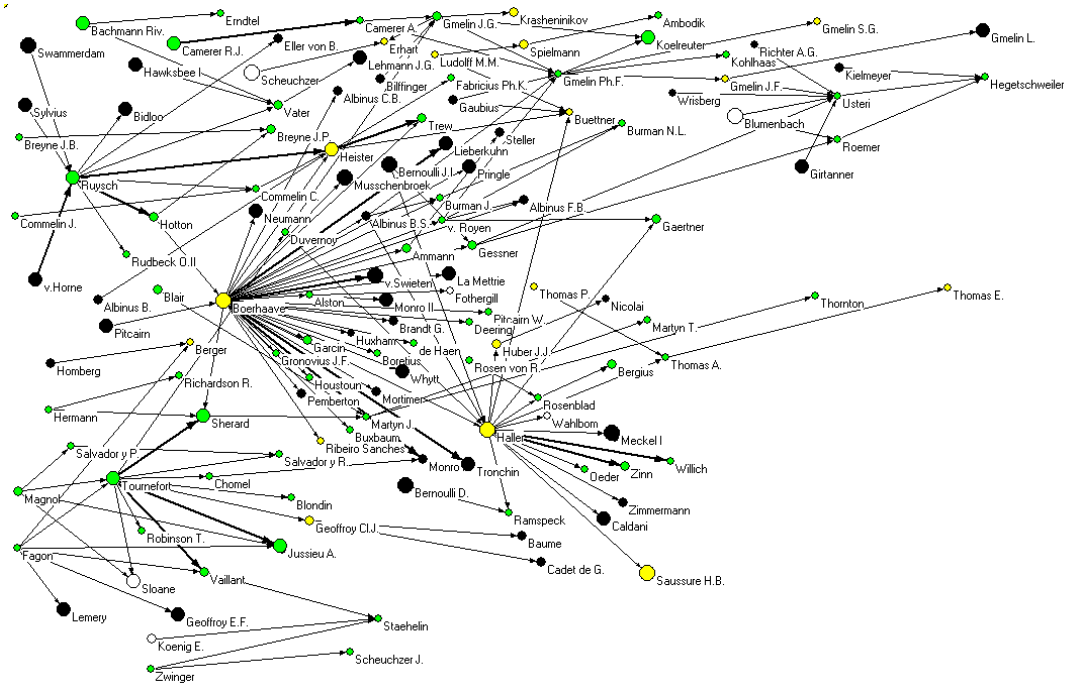


Figure 3. Training links within the mixed subset. The specialized botanists are in green, the non-specialized in yellow, the occasional in white; other men of science are in black. Sizes of the vertices are proportional to the importance of the scholar, according to formal criteria of academic affiliations (0; 1; 2 or more, among the six majors) and presence or absence in biographical dictionaries (DSB, Macmillan, Gascoigne 1994). Spots are located chronologically from the early 17th to the late 18th century.

In the early 18th century, Boerhaave exemplifies the tradition of teaching botany within medical colleges or faculties. This had been the case from the mid-16th century, especially in some Italian universities (Bologna, Padova, Pisa) and somewhat later in most German high schools , France, Netherlands and Sweden. In most of these universities, domestic students were joined by young scholars of foreign nations practicing the *peregrinatio academica*. For those who pursued scientific investigations after the end of their formal training, the contacts established during their studies with professors and fellow students would largely shape their later status or position within the informal Republic of letters and sciences.

The dominant position of Boerhaave also shows the importance given to botanical knowledge in the Low Countries since the time of their independence, and even before. This importance was linked with the agricultural applications and commercial uses of plants as well as with their medical virtues. Founded in 1587, the botanical garden of Leyden (*Hortus academicus*), epitomized the long standing interest of the United Provinces for new plants and flowers, an interest which had symbolically culminated in the famous "tulip crisis" of 1637. Therefore, the various training opportunities provided by some botanical gardens of the 17th and early 18th century appeared as the result of a well-established tradition, and the same is true for Dutch medical schools. At Leyden University, botany had been illustrated before Boerhaave by Paul Hermann, professor between 1679 and 1695, and by Petrus Hotton, professor between 1696 and 1709. Other strongholds of botany existed in the botanic garden of Groningen (founded in 1641) and in the *Hortus medicus* of Amsterdam, founded in 1684. His first curator Jan Commelin (1629-1692) started a brilliant line of botanic teachers at the *Athenaeum Illustre* that included the anatomist Frederik Ruysch (prof. 1681-1728), Jan's nephew Casper Commelin (prof. 1706-1731), Johannes Burman (prof. 1728-1779) and his son Niklaas Laurens Burman (prof. 1780-1793). With seven recorded disciples, Frederick Ruysch indeed appears as one of the most central figures of our sample.

Figure 3 also shows the double status, national and international, of Tournefort. First as student of Magnol in Montpellier and Guy Fagon in Paris, then as teacher of Sébastien Vaillant and Antoine de Jussieu, Tournefort was a key connecting figure in the establishment of a French tradition of classification of species. He also had an international dimension as teacher of William Sherard in England and Johann Georg Duvernoy in Germany. This latter in turn taught Johann Georg Gmelin, who later trained botanists such as Joseph Gottileb Koelreuter, Philip Friedrich Gmelin and the Russian geographer and botanist Stepan Krasheninikov.

For the development of botany as a science of classification of plants, the importance of Tournefort's system was probably much more decisive than Boerhaave's teaching. Yet, a great part of his influence obviously went through channels other than direct teaching. As for Haller, who was professor in Göttingen between 1736 and 1753, he was like Boerhaave a leading figure of medical teaching even more so than of botany. His eminent place in the mixed subset underlines the crucial presence of German and Swiss botanists

The French subset

The second subset (by chronological order) shows a surprising national homogeneity with 65% of French botanists and of 15% French-speaking Swiss, in fact Geneva citizens such as Candolle who spent the whole Napoleonic era under French rule. This national character, in sharp contrast with the international recruitment of the mixed subset, is reinforced by the dense interconnections existing between its members (**Figure 4**). Yet, the structure of this subset requires a closer examination before concluding at the existence of a national community of botanists in late 18th - early 19th century France.

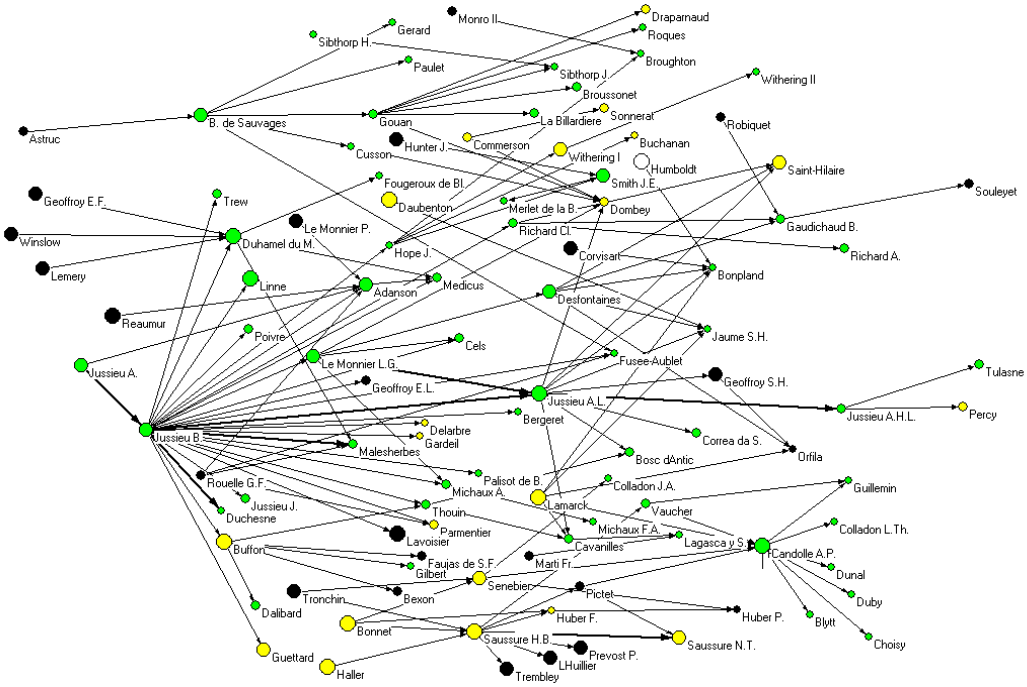


Figure 4. Training links within the French subset. Spots are located chronologically from the mid-17th to the early 19th Century.

According to the number of disciples, the French community of botanists was dominated in the 18th century by the Jussieu dynasty, especially Bernard (with 27 disciples) and Antoine-Laurent (with 8), and to a lesser extent Antoine (4). Other outstanding professors and masters include Louis-Guillaume Le Monnier (5 disciples) and Lamarck (5) in Paris, François Boissier de Sauvages (5) and Antoine Gouan (7) in Montpellier, as well as Augustin Pyramus de Candolle (7) in Montpellier and Geneva. Therefore, the domination of Paris, focused on the *Jardin du Roi*, the *Académie des Sciences* and the garden of Trianon in Versailles, was not exclusive.

Until the late 17th century, the garden of the medical faculty of Montpellier, founded in 1597[8], was in a position to contest the supremacy of the *Jardin du Roi* in Paris, founded in 1635[9]. It was in Montpellier that Magnol made the first attempt at a natural classification of plants. It was also in Montpellier that Tournefort first studied, under Magnol, before becoming the pupil of Fagon in Paris. The same path leading from Montpellier to Paris was followed by Antoine de Jussieu, before he taught botany at the *Jardin du Roi* (1710-1758).

In the early 18th century, the development of a French tradition of botany benefited from the publication of Tournefort's system of classification (1694) and the demonstration of plant sexuality by Vaillant (1717) (Williams, 2001). The *Jardin du Roi*, the *Académie des Sciences* and some lesser institutions allowed for a concentration of specialists in Paris, which had no equivalent elsewhere. After the death of Antoine de Jussieu (1758), Louis-Guillaume Le Monnier taught botany at the *Jardin du Roi*, but it was Bernard de Jussieu (1699-1777), head of the garden of Trianon, who trained the most famous students and among them Le Monnier, Buffon, Adanson, Guettard, Duhamel du Monceau, Thouin, Claude Richard, Antoine Richard as well as his own nephew Antoine-Laurent de Jussieu. It was also at the Trianon garden in Versailles that Bernard de Jussieu, helped by the gardener Claude Richard, first developed his natural classification of plants. This classification, based on the anatomy of plants and a hierarchy of characters, would later be applied to the *Jardin du Roi* by Antoine-Laurent de Jussieu (1774), before he published its principles in the *Genera Plantarum* (1789). It would then become the landmark of a new school of botany introduced by Candolle in Switzerland, by Robert Brown in Great-Britain, by Kunth in Germany and by Cavanilles in Spain.

Be it as it may, teaching institutions and intellectual developments of botany did rarely have a national character, even in France. As a matter of fact, the leading botanists of Montpellier (Boissier de Sauvages, Gouan, Broussonet, La Billardière) ignored Jussieu's natural classification of plants until it was introduced by Candolle after 1808. In Geneva, the local botanical tradition mainly consisted of the vegetable physiology illustrated by Bonnet, Senebier and Saussure junior until Candolle's return in 1816 who promoted a local school of natural taxonomy. In the other French provinces, the Linnean tradition would long remain the dominant school (Duris, 1993) as it was in most countries outside France.

[8] The royal decree was issued in 1593.

[9] The royal decree was issued in 1620 and the effective opening happened in 1640.

The Swedish-Germanic subset

The third subset, whose members are quite contemporary to those of the French subset, is clearly focused on the figure of Linné, whose number of disciples reaches 31. The fact that Linné was professor of medicine and botany at the University of Uppsala between 1742 and 1776 suggests many parallels with Boerhaave's professorship in Leyden. Yet, the separation between botany and medicine had in the meantime acquired some consistency. Linné himself did not inherit from of a national tradition of botany as strong as the Dutch one before Boerhaave, although he had a few Swedish forerunners such as Olof Celsius or Olof Rudbeck father and son. In fact, Linné's sexual system of classification was developed in a period of strong interest for useful sciences, promoted since 1739-41 by the Swedish Academy of Sciences (Frängsmyr, 1989). By that time, the main goal of botany had already shifted from the knowledge of medicinal herbs to the identification and classification of species of all origins, often with their economic uses in mind (Fries, 1950). Because of this focus on classification, the closest science to botany had become natural history instead of medicine. Therefore, most of Linné's outstanding pupils were botanists or naturalists instead of anatomists, physiologists or pathologists (**Figure 5**). If we consider the most renowned ones, two thirds can be considered as specialised botanists (Forsskal, Joerlin, Loefling, Rolander, Lidbeck, Martin, Alströmer, Afzelius, Hellenius, Acharius, Bergius, Thunberg, Dryander, Murray) and the remaining third as naturalists (Kalm, Hasselquist, Osbeck, Ascanius, Wahlbom, Montin, Solander). Another difference with Boerhaave is that Linné's investigations were framed in a national context, so that most of his disciples were Swedes, or at least Scandinavians. Compared with the French subset, his disciples were more often second-rank scholars. Yet, in the whole subset, the proportion of specialised botanists was higher than in the French subset.

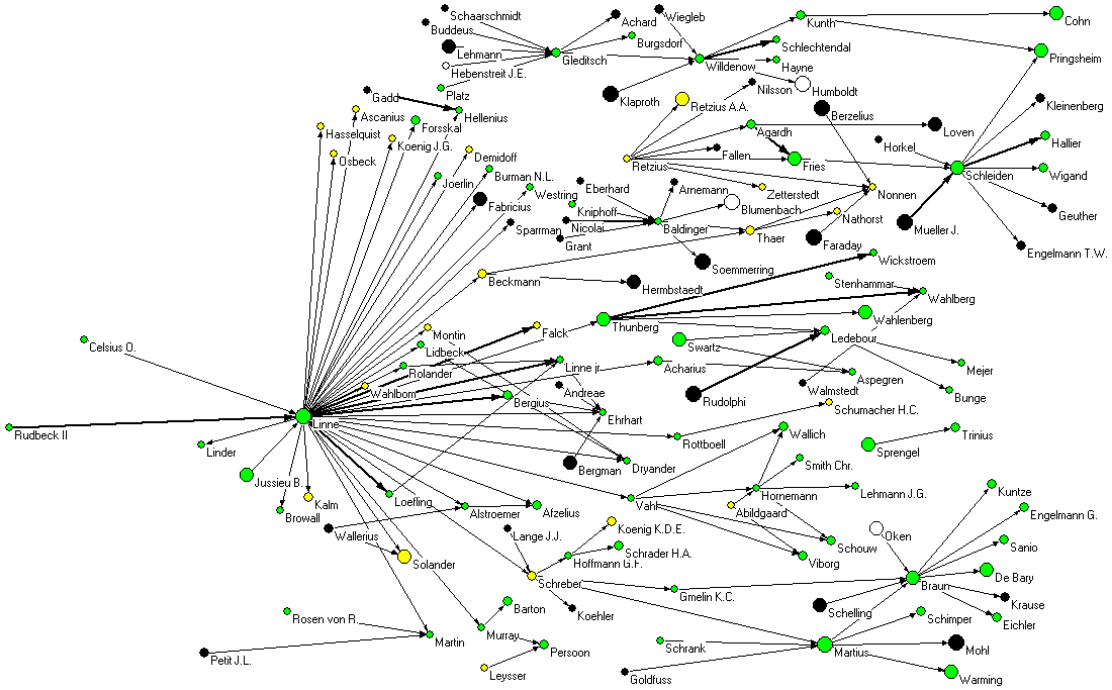


Figure 5. Training links within the Swedish-Germanic subset. Spots are located chronologically from the late 17th century to the mid-19th Century.

Finally, the density of interconnections shows another interesting feature. If this density appears high among the Swedish botanists around Linné, and to a certain point around his disciple Thunberg (who had 6 disciples), the connections become less frequent between the other actors of the sub-group, either German or Danish. Figure 5 shows that German botanists of the subset spread out at least in three distinct directions: a fourth one went through the Dane Martin Vahl, who had himself four disciples.

One of the Linnean offsprings in Germany had indeed a mainly Swedish character. It first went through Thunberg, successor to Linné's son at the chair of medicine and botany in Uppsala, who trained Karl Friedrich Ledebour (1785-1851) as well as Swedish botanists such as Wahlenberg, Wickström, and Wahlberg. Ledebour, who headed the botanical garden of Greifswald, in Swedish Pomerania, was himself born in Greifswald, where the diffusion of Linneism benefited from a specific cultural context (Önnerfors, 2008). He later moved to Dorpat, where he taught natural history to Russian and Baltic students such as Karl Andreevič Mejer and Alexander von Bunge.

The second and most important Linnean filiation in Germany went through Johann Christian von Schreber (1739-1810), who taught medicine and botany at the University of Erlangen (Bavaria). Three of his students are worth mentioning as illustrations of the diverging destiny of the Linnean school in Germany. One is Karl Christian Gmelin (1762-1837), who taught botany at the Karlsruhe Gymnasium and remained a classical Linnean. The second is Georg Franz Hoffmann (1766-1826), who taught botany in Göttingen (to Heinrich Adolf Schrader, Karl Dietrich Koenig, but also to Goethe and Humboldt), and later in Moscow. As a specialist of cryptogams, he could make little use of the Linnean classification. Karl Friedrich von Martius (1794-1868), a third student of Schreber and another specialist of cryptogams, was exactly in the same position and can therefore not be counted as a true Linnean. As professor of botany in Munich, he taught Karl Friedrich Schimper, morphologist and founding father of phyllotaxy, as well as Alexander Carl Braun, who would become the major representative of German *Naturphilosophie* in the field of botany.

A third and even less orthodox Linnean descent line in Germany went through Johann Beckmann (1739-1811), who taught economy and headed an agronomic garden in Göttingen. His most famous disciple was the agronomist Albrecht Daniel Thaer, who established his own agronomical institute in Möglin near Potsdam.

The example of Linné's descent in Germany illustrates once again the fact, concerning the bicomponent, that individuals of each generation are submitted to crossed influences, which produce new combination of ideas and ensure the continuous reinterpretation of any scientific tradition. In the case of Germany, the diverging interpretation of Linneism may have been reinforced by the multiplicity of botanical centres. Be it as it may, the original elements of Linné's sexual system had been so transformed in the late 18th and early 19th centuries that they were hardly recognizable among the third generation of his disciples.

4. Interpretation of the observed features

The distribution of master-disciple relations within the three above-defined subsets shows the dominance of a few institutions as entry ways to the field of botany, and the role of these institutions in the genesis of national communities of botanists, or at least in the aggregation of first cores of indigenous specialists. Within the French subset, the *Jardin du Roi* attracted most of the future French botanists of some importance, without drowning them among foreign students. The same can be said of the Uppsala medical faculty within the Swedish-Germanic subset, although Linné's disciple are not exclusively Swedish or subjects of the Swedish empire, yet also

include a significant proportion of Germans and Danes. As for the Dutch botanists, they all belong to the mixed subset, but build only a minority among the botanists of some repute trained in Leyden. The consideration of master-disciple relations within further "national" contexts (Great Britain, "Italy", "Germany", Switzerland) shows at least two further trends. One is the mediocre impact of British and Italian institutions on the training of European botanists, and the apparent isolation of insular and peninsular specialists of plants. The other is the wide variety of training places that German and Swiss botanists disposed of in their own country or abroad.

After an investigation of these specific national contexts, we shall go back to the contrasted features of the three main subsets, in order to frame an explanation of the dynamic tendencies that shaped the evolution of botany between 1670 and 1830. The changing qualifications of the whole set of botanists, and their choices of new training places and methods, will be considered as indicators for long-term trends, and also as possible explanations for the observed changes.

The isolation of British and Italian botanists

Considered from the point of view of the recorded training links, most of the 18th century British botanists appear as isolates, although some are present in the mixed subset as well as in the French subset. When taken separately, the British botanists give the image of a scattered community, where interconnections are rather sparse (**Figure 6**). This image of a "loose" community given by botanical training has many explanations. The most obvious one is the rarity of university chairs of botany: only twelve holders for the whole period 1700 to 1830 figure in our British set, against 14 professors of botany in France (most of them in Montpellier and in other provincial cities), 24 in Italy and 38 in Germany. Among the British professors of medicine, only three were botanists (none of them headed a botanical garden) compared to six in France, six in Italy and 34 in Germany. At English universities, the whole medical training was indeed rather weak. This weakness was largely compensated by the teaching provided by the London hospitals, but it was less true for the specific field of botany. On the university level, the Cambridge professor of botany Richard Bradley (who taught between 1724 and 1732), as well as his successors John Martyn (prof. 1733-1761) and Thomas Martyn (prof. 1761-1825), remained in the shadow of their colleagues in the physico-mathematical sciences (Gascoigne, 2002). They even abandoned teaching after a few years of mediocre success. In Oxford, the brilliant heritage of Johann Jacob Dillenius (professor between 1734 and 1747) was wasted away by Humphrey Sibthorp, who taught one single time in nearly 40 years (1747-1783) as well as by his son John Sibthorp, who did not train any disciple of fame in

his twelve years of professorship (1784-1796). In Edinburgh, where the medical school enjoyed a wide international reputation, the teaching of medicine was in closer association with physiology and chemistry than with botany. The modesty of its successive botany professors (Charles Alston, John Hope, Daniel Rutherford) may be partly responsible for this statement of fact, even though John Hope (professor between 1760 and 1786) was able to command attention of domestic or foreign students. He figures in our network with four disciples.

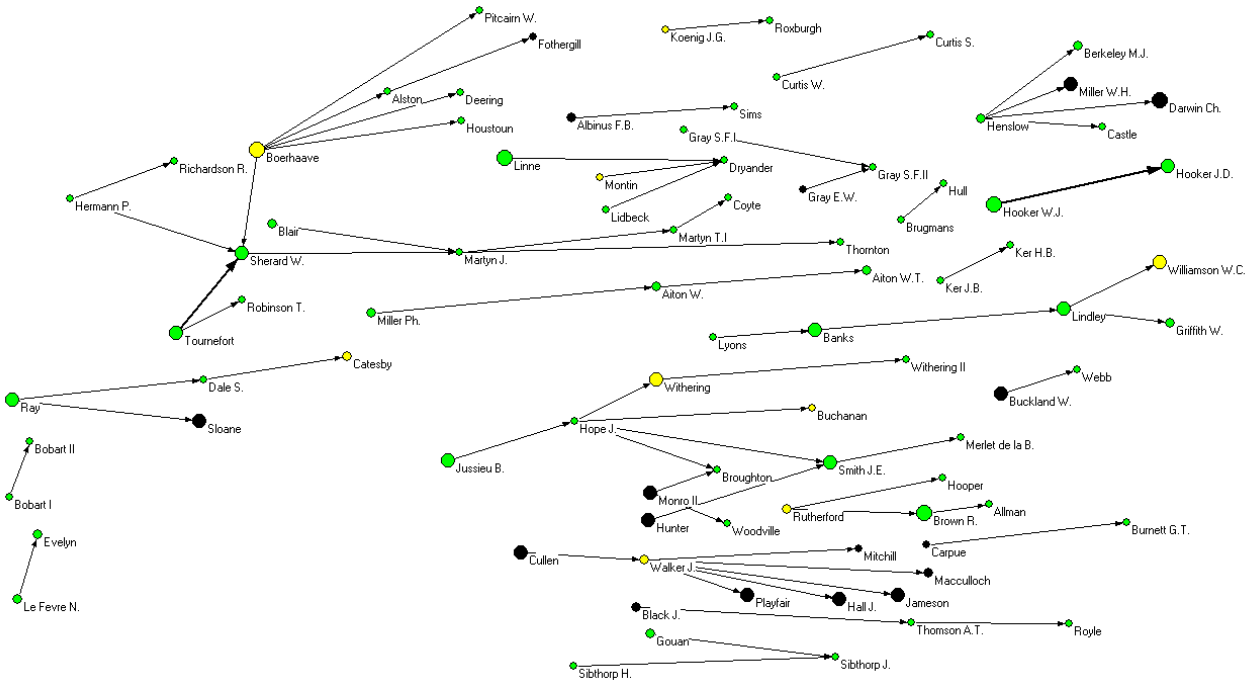


Figure 6. Training links among the main British botanists. Spots are located chronologically from the early 17th to the early 19th century.

On the other hand, a significant fraction of the British botanists, especially the most privileged ones, trained at foreign universities. Some also used the teaching facilities provided by the Chelsea Physic gardens (founded in 1673) and the Kew gardens (founded in 1760). Yet, the high proportion of gentlemen farmers and clergymen living on the countryside and therefore not in a position to train students or disciples, may provide another explanation for the rarity of training links between British botanists. In our set, the proportion of specialists of plants living from their estates, rents or ecclesiastic incomes is of 23% (at a minimum), a high ratio compared to Italy (14%), France, Germany and other countries (7 to 8%)[10]. Another feature so typical for British botany in the 18th century is the high number of enlightened

[10] However, it may be possible that the inclusion of agronomists would raise the proportion of gentlemen farmers in France, Italy and other countries as well.

gardeners such as John Evelyn, Thomas Knowlton, James Lee, James, Dickson, Archibald Menzies, James Forbes, Robert Sweet, John Loudon, George Sinclair, William Baxter, George Don, John Smith, Joseph Paxton, and of course William and William Townsend Aiton. Nearly all of them were isolates in matter of formal training. A few bear witness of the links between British botany and the emergence of the Empire.

The Italian case is characterized by an even stronger scarcity of training connections. Italian botanists are nearly absent from the main weak component and from its various subsets. The poor state of biographical data available in WBIS provides a plausible explanation, since the proportion of botany professors was much higher in Italy (49% in our set) than in France (15%) or in Britain (9%). It was even higher than in Germany (25%) and in other countries such as Sweden, the Netherlands, Switzerland, Russia or the United States (with an average of 24%). Yet, the explanation provided by historiography is only a partial one, since Italian medical and philosophical faculties were evidently at pains to attract European students in botany. The existence of a specific chair for botany (and often agriculture) in many Italian universities was therefore not a guarantee of high standard in botanical training. In fact, most of the chairs were recent creations of the early 19th century, and they helped the number of Transalpine botanists to increase again, after a long period of silent decline. Many of these new chairs had also a strong practical character, in connection with the backward situation of Italian agriculture. As for the older botanical gardens, linked to the medical faculties of Pisa, Padova, Bologna and Florence, they had lost much of their traditional power of attraction. In the 18th century, time was obviously over when European botanists came to Italy in order to rediscover the Antique textbooks of Theophrastus, Pliny and Dioscorides, or to participate to the Renaissance of natural history on the sides of Aldrovandi, Calcolari and Cesalpino. In places like Bologna, Pisa or Florence, provincial botany was still productive, but Transalpine scholars, obsessed by their contest for regional or national supremacy, tended to lose sight of their European peers.

The multiple centres of German botany and the evolution of traditions

If provincialism seems an important feature of the Italian communities of botanists, let us examine the situation within the German states of the Holy Empire. The teaching of botany obviously benefited from the existence of a dense university system that often associated professorships in medicine with the management of a botanical garden. Despite political fragmentation, German students in medicine were often attending two, three or four universities consecutively. This attitude, nearly

unknown to Italian students, contributed to lower the barriers between physicians and scholars belonging to different German states. Would-be German botanists did not even hesitate to study abroad, so that before 1780, their presence in the lecture halls of Leyden and Uppsala was nearly as frequent as in the medical faculties of Göttingen or Leipzig, in the Berlin *Collegio Medico-chirurgicam* or in the Karlsruhe *Gymnasium*. Their presence in the mixed and in the Swedish subsets requires no further explanation.

A graph of the training links between German botanists confirms the existence of many different centres of botanical learning, as well as the importance of a few scholars such as Albrecht von Haller in Göttingen (12 disciples), Anton Wilhelm Platz in Leipzig (7 disciples) and Karl Ludwig Wildenow in Berlin (4 disciples) (**Figure 7**). Up to a certain point, these centres also had different scientific orientations, even though the migration of students and professors tended to reduce these differences. Further, it is interesting to consider what the inclusion of a few individuals in the Swedish subset did mean and how Linné's teaching was thus reinterpreted in various local contexts.

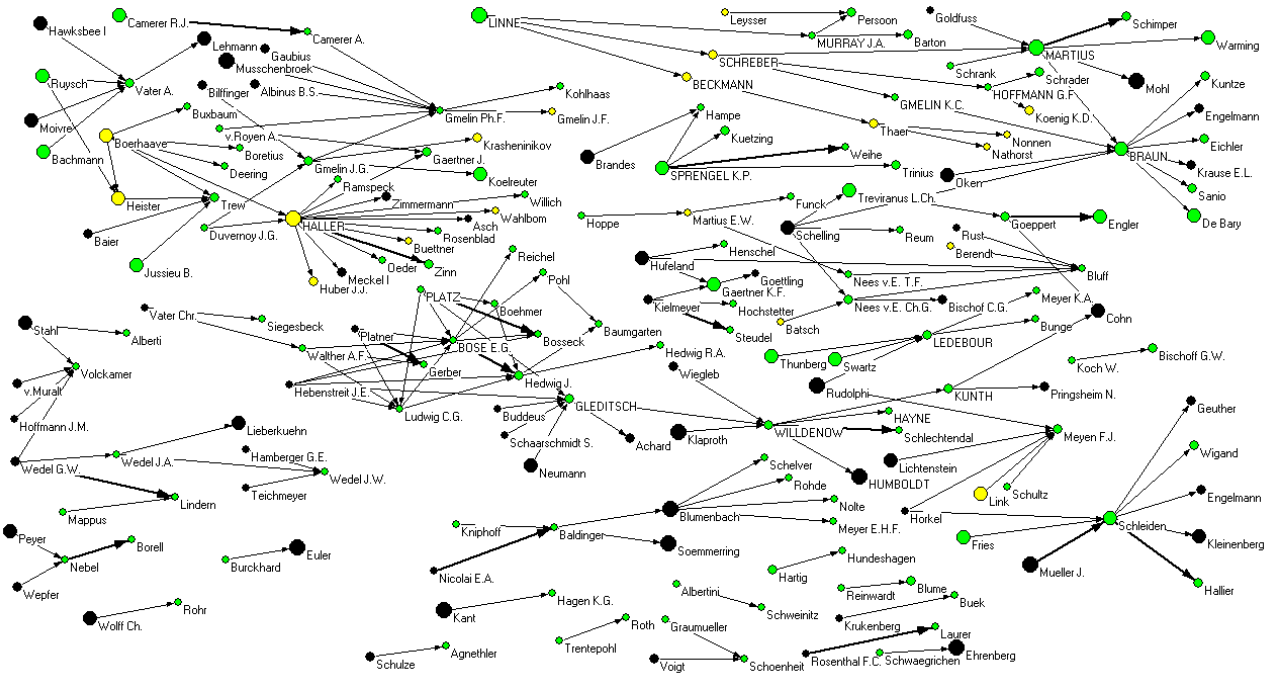


Figure 7. Training links among the main German botanists. Spots are located chronologically from the mid-17th to the mid-19th century.

Thanks to Albrecht von Haller, who created its botanical garden (1737), the Göttingen medical faculty immediately became a centre of botanical teaching in the medical tradition of Boerhaave. In the last third of the 18th century, it had become a

stronghold of Linneism, taught between 1769 and 1791 by Linné's disciple Johan Anders Murray, and between 1792 and 1803 by Georg Franz Hoffmann (1792-1803), who had been a pupil of Linné's disciple Johann Christian von Schreber in Erlangen. Yet, Murray's most reputed disciples were not Germans, but the Dutch Christiaan Hendrik Persoon and the influential American Benjamin Smith Barton (who has eight disciples within our set). As for Johann Beckmann, another of Linné's disciple established in Göttingen, he taught economy between 1770 and 1811, so that his intellectual posterity mainly consisted of agronomists such as Albrecht Daniel Thaer or chemists like Sigismund Hermbstaedt.

Between 1770 and 1810, Göttingen's influence as genuine centre of Linneism in Germany was challenged by Erlangen, where Linné's disciple Johann Christian Schreber trained the above-mentioned Georg Franz Hoffmann (later professor in Göttingen), as well as Karl Christian Gmelin (later professor in Karlsruhe) and Karl Friedrich von Martius (later professor in Munich).

Leipzig was another stronghold of the botanico-medical tradition since the time of Anton Wilhelm Platz, who taught botany between 1733 and 1754 and medicine between 1754 and 1784. His successors as professors of botany were Ernst Gottlob Bose (between 1754 and 1773), Johann Ehrenfried Pohl (1773-1788), who were both trained as physicians and became later professors of medicine. Johann Hedwig on the contrary taught medicine first (1786-1788) and botany later (1788-1799), reversing thus the traditional hierarchy of academic chairs.

In Halle too, botany remained in the shadow of medicine until 1795, when Kurt Polycarp Sprengel became professor of botany and director of the botanical garden.

In Berlin, Linnés' sexual system of classification was introduced after 1746 by Johann Gottlieb Gleditsch (1714-1786), a former student of Platz in Leipzig but who had no direct contact with the Swedish master. His disciple Karl Ludwig Willdenow (1764-1812) had himself reformed Linné's obsolete classification in his *Grundriss der Kräuterkunde* (1792) before he became one of Gleditsch's successors as head of the Berlin botanical garden (1801-1812). After the foundation of the University of Berlin in 1810, three of Willdenow's students would be called in turn to teach botany in the capital city. The first one, Friedrich Hayne (1763-1832), taught the modified Linneism of his master between 1814 and 1829. The second one, Karl Sigismund Kunth (1788-1850), who made of Berlin the main centre of German botany, introduced after 1829 the natural classification of plants. As for the third one, Carl Alexander Braun (1805-1877), who taught for many years in Karlsruhe and in Freiburg, he was known as an advocate of *Naturphilosophie*.

This short intellectual overview of the fate of Linneism in Germany shows that if the master-disciple relations indeed condition the entrance into the Republic of Botanists, they do not determine the subsequent intellectual evolutions of its members. Intellectual influences, which obviously flow through a multiplicity of channels (publications, translations, mutual exchanges), produce new combinations at each generation, continuously transforming the outlines of any school of thought.

The contrasted characters of the three subsets

If the cases of Britain, Italy and Germany give information about the semi-peripheries of the 18th century Republic of botanists, the characters of three subsets that dominated the master-disciple relations allow to identify the changes underwent by its deeper core during the same period, especially in the five or six decades that elapsed between the zenith of the mixed group (around 1710-1720) and the apogee of the French and the Swedish groups (in the 1770s).

For the members of the "mixed subset", a high-level training in botany often meant a long distance move across national or linguistic borders. Entrance into the networks of the Republic of Letters was also conditioned by the traditional practice of "*peregrinatio academica*". A closer look at the structure of this mixed subset shows that it is subdivided into three or four subgroups dominated by the figures of Boerhaave, Haller, Tournefort and Ruysch. All of them taught to international audiences, despite the existence of a backbone of national students from France, the German states or the Dutch provinces. Strikingly, Italy, which had dominated botanical training in the 16th century and in the early 17th, was no more part of the picture. As for the British botanists, they appear among the followers of Tournefort and Boerhaave. Another sign of the times was the maintained association between botany and medicine, especially *materia medica*, a factor that explains the high proportion of physicians and medicine professors within the mixed subset. This proportion, of 71% by the beginning of the botanists' careers, is significantly reduced to 38% by the end of it. In a symmetric way, the proportion of "professional" botanists (royal botanists and botanists *pensionnaires*, professors of botany, gardeners) within the same subset increases from 15% for the first stable position to 45% at the end of the *cursus honorum*.

From a chronological point of view, the two other subsets have to be considered simultaneously as characteristics of the situation prevailing in the second half of the 18th century. The French subset, which can be seen as the prolongation of the earlier Tournefort subgroup, is mainly based on the unique institutional setting provided by the *Jardin du Roi* and the *Académie des Sciences* in Paris, and in a subsidiary manner

by the medical faculty of Montpellier. The proportion of medical professions in it is of 25% at the beginning of careers (against 71% in the mixed subset) and of 15% by the end of their careers (against 38%). The proportion of "professional" botanists on the contrary rises to 29% (against 15%) at the beginning of their careers and to 51% (against 45%) by the end. Breaking with the traditional association of botany with medicine, a handful of pensioned academicians, botanic demonstrators and keepers of herbaria could practice botany as full-time specialists and create a critical mass of interconnected professionals. The outstanding achievements of the Jussieus, that of the development of a natural classification of plants, benefited from these favorable circumstances.

Clearly focused on the figure of Linné and on his sexual system of classification, the Swedish-Germanic subset has a less marked national character than the French one, even though Swedes and Danes account for 60% of its members. If the traditional association between botany and medicine had also been loosened compared to the time of Boerhaave, the science of plants had not reached the degree of autonomy existing within the French subset. Indeed, the number of physicians and representatives of other medical professions was 41% at the beginning of their careers and 22% later in life, a situation close to the average between the mixed and the French subsets. On the other hand, the degree of professionalism of botanists was quite the same in the Swedish as in the French subset with 30% at the beginning of their careers and 53% by the end. Apparently, Linné's program of description of the richness of Creation and identification of the numerous vegetal commodities available to mankind and the nation stimulated the professionalization of botany. Compared to the French subset, the Swedish-Germanic subset includes fewer representatives of the Ancien Régime upper and middle classes (landowners, priests, lawyers, civil servants), and probably also fewer individuals engaged in trade, manufactures, craftsmanship and other middle classes professions. In spite of a stronger presence of professors, the proportion of first-rank men of science, and particularly of academicians, is lower than in the French subset. Linné's simpler method of classification obviously secured a wider popularity to his system, especially among second-rank botanists and even more among amateurs (Duris, 1993). Yet, its frequent association with natural history in order to meet utilitarian ends linked to agriculture or to pharmacology, may have produced a less "academic" style of botany than the one practiced by the Jussieus and their disciples.

Global evolutions and national contrasts

The global evolutions affecting the whole set of botanists confirm the features observed on the subsets of well-connected botanists. They also underline some structural differences between national systems of scientific education. Medical studies for instance characterized no less than 67% of the botanists trained before the 1740s (that is born before 1720), a proportion which decreased to 55% for those trained between 1740 and 1780 (that is born between 1720 and 1760) and to 50% after 1780 (i.e. born between 1761 and 1805). Conversely, the figure of scholars trained in philosophy, or in science, which was rather low before the early 1740s, was growing with the creation of new teaching positions in many philosophical faculties and botanical gardens. For botanists trained in the period of the Enlightenment properly speaking (between 1740 and 1780), the most striking features are the growing audience of the *Jardin du Roi* in Paris, but also the more frequent involvement in botany of persons trained in arts, in law and above all in theology. Finally, the period between the early 1780s and the late 1820s is characterized by the higher ratio of botanists trained in science, with the development of university teachings in science, especially within the German faculties of philosophy. The most visible result of this institutional development is the increased ratio of major German botanists ("A") among the specialists of the third period: they represent 34% of this elite after 1780 against a small 6,5% in the first period (before 1740) and a puny 4% in the second period (between 1740 and 1780). If one considers the whole community of botanists "A" and "B", the ratio of Germans increases in more modest proportions, from 31% and 26% in the first two periods to 36% in the last period.

Another global evolution affects the international mobility of young educated botanists. Recorded movements across "national" areas show a declining trend as the century goes on. During the first period (before 1740), at least 20% of botanists spent one semester or more at a foreign university, a proportion that was reduced to 14,5% in the second period and to 9% in the third period. For the botanists who made the essential part of their studies abroad, the proportion was of 13% in the first period, of 10% in the second and 5,5% in the third period. And as for the proportion of future botanists who studied in more than two different universities (*peregrinatio academica*), it was of 13% in the first period, but declined to 7% in the second period and to 6% in the third period. The long term tendency was therefore to reduce the international, but also the intra-national mobility of students in medicine or science, at least for those who would later engage in serious botanical investigations. The increasing national, but also local, character of botanical training

seems therefore beyond doubt.

A possible consequence is that the availability of specific courses in botany and natural sciences of development in a wider number of European cities and countries, did not reduce the differences between training systems in the 18th century. If we consider the evolution of qualifications of botanists between 1670 and 1830, and their choice of universities and other training places, a striking contrast opposes German or Italian scholars on the one hand, that is residents of states with highly developed university systems, to French and British scholars on the other, who were mainly trained in royal or corporate botanical gardens.

In the case of Germany, the importance of the traditional university system explains the very high proportion of medically trained botanists in the first two periods (80 % and 66%) and even in the third one (50%). In this third period, the growing opportunities for botanists to be trained as scientists in philosophy favoured the choice of modernized universities such as Göttingen, Berlin and Erlangen-Munich to the detriment of the more traditional Leipzig, Altdorf or even to the foreign Leyden. In Italy as well, the high density of university departments explains the fair proportion of medically trained botanists in the periods two and three (66% and 60%). In the third period, the creation of new chairs of botany explains the sudden rise of Italian specialists of plants and agriculture (from 11 and 9 in the first two periods to 23 in the third one). On the contrary, the decline of Dutch botany between period one and two (from 10 to 5 specialists) and of Swedish botany between period two and three (from 18 to 9 specialists) seem closely associated with a stagnation of the national universities of Leyden and Uppsala, at least in the field of botany and natural sciences. The same may be true for Basel in Switzerland in the third period, even if its decline was largely compensated by the rise of Geneva.

In France, the decline of Montpellier medical school in the second period (Enlightenment) was compensated by the rise of the *Jardin du Roi*, so that the number of new botanists for each period remains steady (from 34 in the first period to 30 and 30 in the latter two). In the third period, the exclusive domination of Paris in matter of botanical training did not produce the same renewal than in Germany (from 48 and 41 in the first two periods to 97 in the third one) or in Italy, despite the creation of the imperial university and the extraordinary development of new medical institutions. In the early 19th century, the main representatives of the natural classification imagined by the Jussieus (such as Candolle, R. Brown, Kunth, Cavanilles) were indeed located in foreign countries. As for the British botanists, we know that many of them were trained abroad in the first two periods. Among those

who studied in British universities, most followed a *curriculum* in arts, theology or law, all studies considered suitable for non-professional gentlemen or non-specialized naturalists. They were joined by the numerous skilled gardeners and nurserymen, who did not attend university colleges.

5. Conclusion

Developing a social network analysis about the history of 18th century botany is a complex task, which implies focussing on the emergence of a new disciplinary paradigm instead of describing a succession of discoveries and theories. This change of perspective makes some known facts appear under a new light, usually highlighting them as results of personal and intellectual interactions between scholars. Other facts, new trends and shifts may also be reassessed or even discovered thanks to this new approach. The present article is an illustration of both perspectives.

The opposition between the Linnean system and the natural method of classification obviously belongs to the known facts. In this case, the new perspective consists of showing the phenomenon as a result of two national training systems – one in France, one in Sweden – in which botany was taught independently from medicine. Yet, the emancipation of would-be botanists from the nearly compulsory training in medicine, and from medical practice, was a global tendency. It was especially visible in Germany, with the development of scientific teaching in the philosophical faculties. It also appeared in Great Britain, with the new training opportunities provided by the Edinburgh University and by various London botanical gardens, and even in Italy, with the renewed interest of universities for agriculture.

Another well-known trend is the interest of Enlightenment thinkers and intellectual elites for utility and for the contemplation of nature in general, and the fact that this intellectual climate impelled a growing number of gentlemen, priests and professionals trained in arts, theology and law to practice botany as a life-long vocation. The predictable – yet never stated so far – consequence is that the number of paid positions for botanists doubled between 1700 and 1770, and again between 1770 and 1830, so that better training opportunities became available in a growing number of countries and cities all over Europe. Therefore, the need to move to foreign countries, or even to other universities within the same national area, was constantly reduced to the benefit of local or national institutions and communities. The nationally mixed character of the early 18th century botanists, which were mostly trained in the Netherlands (Leyden, Amsterdam), gave way, in the second half of the

century, to a more diversified training pattern, dominated by a French group based in Paris and a Swedish-Germanic group trained in Uppsala. These two famous groups, who served as nucleus to national communities of botanists, were only the most visible examples of an emerging set of geographically defined communities of scholars. An improved documentation as well as more refined techniques of investigation shall allow us to detect the existence of further communities of botanists, either national or local.

Of course, botanists without recorded training links remained frequent in 18th century Italy, Great-Britain, Germany, as well as in the Habsburg dominions and even in the provincial cities of Sweden and France. On the other hand, the French living in Paris and in Montpellier were closely connected together, as were the Swedish botanists of Uppsala, Stockholm, Lund and Abo, the Dutch of different provinces and the Swiss, either German-speaking (connected to the mixed group of Boerhaave) or French-speaking (close to the French group of the Jussieus). Yet, the consideration of other kinds of links would delineate other botanical communities, either national or not. As a matter of fact, links of patronage were very tight in Great Britain, especially around Joseph Banks (1743-1820) at the time of his life-long presidency of the Royal Society (Gascoigne, 1998), but also earlier around Hans Sloane (1660-1753) and Peter Collinson (1694-1768), and later around William Jackson Hooker (1785-1865). In St-Petersburg, well-paid academic positions allowed the Russian government to import trained botanists from Germany and other countries, whereas the colonial policy of Enlightened Spain offered plenty of opportunities for national botanists to explore the floras of Southern America.

As for the German botanists, they had no national centre, except perhaps Berlin in the 19th century. Before that, the botanic garden of Berlin and the medical faculties of Leipzig, Göttingen and Erlangen all had their leading figures and their climatic periods, even though none of them was able to give a lasting character to its dominant position. The ways in which the Linnean inheritance was transformed in various descent lines after 1770 show the coexistence of different local traditions within the Holy Empire, and at the same time the mutual influences established by the circulation of teachers and students. This context of improved opportunities and increased stimulus was the intellectual background of the emergence of a growing number of first rank botanists after 1780.

While a growing number of universities and botanical gardens provided opportunities for formal teaching in botany as the 18th century went on, no real standardization of training was perceptible before 1830 or so. Quite to the contrary, after 1740, more

diverse actors were trained in university departments other than medicine, and later made careers in other professions than the medical ones, including, of course, botany. The growing influence of utilitarianism and the development of a pre-romantic sensitivity to nature were additional factors of interest for botany among the European scholarly elites. At the same time, the existence of a disciplinary paradigm specific to botany was more and more perceptible, a least for a hard core of professional botanists. Yet, the development of national teaching and research institutions, and the growing competition between monarchies for the "Empire of Science", nevertheless produced a contrasted geography of scientific training and practice. While the international system of ordinary exchanges of information and materials (the "Republic of Letters") remained largely unchanged until the 1780s, the national character of academic science in France and of university reforms in Germany, as well as the utilitarian and imperial policies developed in Sweden, Great Britain, Italy, Russia and Spain all conspired to produce a nationally contrasted geography of scientific settings that affected the development of botany. As for the social practices of field collecting and classification, they also had an important influence on the development of local communities of amateurs and on isolated botanists in provincial and peripheral areas.

Be it as it may, training opportunities and master-disciple relations are little more than the entry way to the world of modern botany. Young scholars willing to reach a professional position or to find means to finance their botanical research had to secure protections from powerful patrons or to enjoy the help of relatives. Their further careers within the "Republic of Botanists" would then be conditioned by intellectual influences, by exchanges of information and specimens, as well as by significant collaborations developed with peers. All these dimensions can be subject to network studies. They are therefore the most likely to reveal additional dimensions of the evolving geography of botanical communities in the 18th century Europe.

References

Batagelj, Vladimir & Mrvar Andrej (1998). "Pajek - Program for Large Network Analysis". *Connections*, n° 21, pp. 47-57.

Bots, Hans & Waquet, Françoise (1997). *La République des Lettres*. Paris : Belin - De Boeck.

Bungener, Patrick (2007). "La botanique au service de l'agriculture. L'exemple des savants genevois" en Paul Robin., J.-P. Aeschlimann & C. Feller. *Histoire et*

agronomie: entre ruptures et durée. Paris : IRD, pp. 285-302.

Bynum, William F., Browne, Janet & Porter, Roy (eds) (1983). *The Macmillan Dictionary of the History of Science*. London: Palgrave Macmillan.

Dauser, Regina, Stefan Hächler, Michael Kempe, Franz Mauleshagen & Martin Stuber (Hg.) (2008). *Wissen im Netz. Botanik und Planzentransfer in europäischen Korrespondenznetzen des 18. Jahrhunderts*. Berlin: Akademie Verlag.

De Nooy Wouter, Mrvar Andrej & Batagelj Vladimir (2005). *Exploratory social network analysis with Pajek*. Cambridge: Cambridge University Press.

DSB: see Gillispie, Charles C. (dir.)

Duris, Pascal (1993). *Linné et la France (1780-1850)*. Genève: Droz.

Elina, Olga (2008). "Private Botanical Gardens in Russia: Between Noble Culture and Scientific Professionalization". *Studies in the History of Gardens and Designed Landscapes*, n° 28 / 3-4, pp. 312-332.

Frängsmyr, Tore (ed.) (1989). *Science in Sweden. The Royal Swedish Academy of Sciences, 1739-1989*. Canton (MA): Watson Publishing International.

Fries, Rob E. (1950). *A short history of botany in Sweden*. Uppsala: Almqvist & Wiksell.

Gascoigne, John (1998). *Science in the Service of Empire: Joseph Banks, the British State and the Uses of Science in the Age of Revolution*. Cambridge: Cambridge University Press.

Gascoigne, John (2002). *Cambridge in the age of the Enlightenment. Science, religion and politics from the Restoration to the French Revolution*. 2nd ed.Cambridge: Cambridge University Press.

Gascoigne, Robert M. (1984). *A Historical Catalogue of Scientists and Scientific Books. From the Earliest Times to the Close of the Nineteenth Century.* New York and London: Garland Publishing.

Gillispie, Charles C. (dir.) (1970-1980). *Dictionary of Scientific Biography*, New York: Charles Scribner's sons (16 vol.).

Girvan, M. & Newman, M. E. J., (2002). "Community structure in social and biological networks". *Proceedings of the National Academy of Science* (USA), n° 99, pp. 7821–7826.

Haechler, Stefan (2008). "Pflanzentransfer in der Korrespondenz Albecht von Hallers

(1708-1777) " en Regina Dauser & al. *Wissen im Netz. Botanik und Pflanzentransfer in europäischen Korrespondenznetzen des 18. Jahrhunderts*. Berlin: Akademie Verlag, pp. 201-218.

Hannaway, Owen (1975). *The Chemists and the Word: The Didactic Origins of Chemistry*. Baltimore: Johns Hopkins University Press.

Hanneman, Robert A. & Riddle, Mark (2005). *Introduction to social network methods*. Riverside (CA): University of California.

Macmillan: see Bynum & al. (eds)

Morton, Alan G. (1981). *History of botanical science*. *An Account of the Development of Botany from Ancient Times to the Present Day*. London: Academic Press.

Müller-Wille, Staffan (1999). *Botanik und weltweiter Handel. Zur Begründung eines natürlichen Systems der Pflanzen durch Carl von Linné (1707-1778.* Berlin: Verlag für Wissenschaft und Bildung.

Nickelsen, Kärin (2008). "Korrespondenzen und andere Netze: Die Konstruktion von Pflanzenbildern im 18. Jahhundert" en Regina Dauser & al. *Wissen im Netz. Botanik und Pflanzentransfer in europäischen Korrespondenznetzen des 18. Jahrhunderts*. Berlin: Akademie Verlag, pp. 113-133.

Önnerfors, Andreas (2008). "Die Verbreitung Linnéscher Naturalhistorie in Swedish-Pommern im 18. Jahhundert" en Regina Dauser & al. *Wissen im Netz. Botanik und Pflanzentransfer in europäischen Korrespondenznetzen des 18. Jahrhunderts*. Berlin: Akademie Verlag, pp. 91-111.

Ridder-Symoens, Hilde de (1989). "Italian and Dutch universities in the 16th and 17th centuries" en C. S. Maffioli & L. C. Pahn. *Italian Scientists in the Low Countries in the 17th and 18th centuries*. Amsterdam: Atlanta (GA), pp. 31-64.

Sigrist, René (2008a). "La République des sciences: essai d'analyse sémantique". *Dix-Huitième Siècle*, n° 40, pp. 333-357.

Sigrist, René (2008b). "Correspondances scientifiques du 18^{e} siècle : présentation d'une méthode de comparaison". *Revue Suisse d'Histoire*, n° 58/2, pp. 147-177.

Sigrist, René (2009). "Scientific Networks and Frontiers in the Golden Age of Academies (1700-1830). An essay with new data" en Helmut Eberhart & Jürgen Barkhoff. *Networking across Borders and Frontiers. Demarcation and Connectedness in European Culture and Society*. Frankfurt a.M.: Peter Lang, pp. 35-65.

Sigrist, René (2011). "On the social characteristics of the 18th century botanists" en André Holenstein, Hubert Steinke & Martin Stuber. *Scholars in Action. The Practice of Knowledge and the Figure of the Savant in the 18th century*. Leiden and Boston: Brill (in print).

Spary, Emma C. (2008). "Botanical Networks revisited" en Regina Dauser & al. *Wissen im Netz. Botanik und Pflanzentransfer in europäischen Korrespondenznetzen des 18. Jahrhunderts*. Berlin: Akademie Verlag, pp. 47-64.

Steinke, Hubert (2008). "Gelehrte – Liebhaber – Oekonomen. Typen botanischer Briefwechsel" en Regina Dauser & al. *Wissen im Netz. Botanik und Pflanzentransfer in europäischen Korrespondenznetzen des 18. Jahrhunderts*. Berlin: Akademie Verlag, pp. 135-147.

Stuber, Martin (2008). "Kulturpflanzentransfer im Netz der Oekonomischen Gesellschaft Bern" en Regina Dauser & al. *Wissen im Netz. Botanik und Pflanzentransfer in europäischen Korrespondenznetzen des 18. Jahrhunderts*. Berlin: Akademie Verlag, pp. 229-270.

Stuber, Martin, Haechler, Stefan, Krempel, Lothar & Ruisinger, Marion Maria (2008). "Exploration von Netzwerken durch Visualisierung. Die Korrespondenznetze von Banks, Haller, Heister, Linné, Rousseau, Trew und der Oekonomischen Geselleschaft Bern" en Regina Dauser & al. *Wissen im Netz. Botanik und Pflanzentransfer in europäischen Korrespondenznetzen des 18. Jahrhunderts*. Berlin: Akademie Verlag, pp. 347-374.

Taton, René (1964). *Enseignement et diffusion des sciences en France au XVIIIe siècle*. Paris : Hermann.

Williams, Roger L. (2001). *Botanophilia in 18th-century France. The Spirit of Enlightenment*. Dordrecht-Boston-London: Kluwer Academic Publishers.

World Biographical Information System (WBIS), edited on microfiches by Saur AG, München (data for European scholars also avaliable on-line).