

Scientific Networks and Individual Performance in Fisheries and Aquaculture Research

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ABSTRACT

Scientific research in Aquaculture and Fisheries, as in other fields, has become a highly specialised enterprise that could not function without the collaboration of the geographically dispersed specialists. Using the ISI Web of Science database of all publications related to Fisheries and Aquaculture for the last 15 years, we investigate the collaboration pattern of scientists publishing in that field.

Co-authorship of academic publications is a strong expression of social linkage in science and will therefore be used as an indicator of collaborative research. By means of Social Network Analysis, the performance of researchers is measured not only according to their numeric output of publications, but also to the number and characteristics of their collaborators.

Using the address information of all publications, we transfer the performance of individual researchers to the institutional level and compile a list of high-performing research institutions for the EU15, Norway and Iceland. Aggregation of co-authored publications to the country level shows the collaboration pattern in European aquaculture and fisheries research.

Keywords: research collaboration, EU15, aquaculture, fisheries, Social Network Analysis

INTRODUCTION

The future of fish production has been a political concern for more than a decade now. Dwindling fish stocks in the seas are facing a dramatically increasing demand for food consumption and processing to fish oil and meal. And while aquaculture could have reduced the pressure on wild stocks, the high use of fish meal for fish farming together with environmental concerns has hindered the development of this sector, at least in Europe. In Asia instead, namely China, aquaculture production has seen growth rates of 11 percent annually since the 1970s (Delgado et al. 2003). There has been considerable contribution of aquaculture to the supply of fish products in Europe nevertheless. Where in many countries fish production from wild catches has declined, farmed products had positive annual growth rates.

There are several ways to enhance innovation. The most important incentive for developing a new production technology is investment in research. The European Commission has invested in modernising of its fishing fleet, in optimising of fishing techniques and improving the political framework. It also has invested in aquaculture technologies. The Commission does so mostly indirectly by funding related research projects. A special European approach in this context is the distinct support for research collaboration within the European Union and with non-EU institutions and corporate collaborators.

The possible ways of evaluating output of the funded research activities are as versatile as the incentives for the research itself. The focus of this paper will be on scientific collaborations measured by co-authorships on published research results in mainly peer-reviewed journals.

Measuring research output of researchers and research institutions by scientific publications is an approved approach to measure performance. The ISI Web of Science is an established institution for providing bibliographic information on peer-reviewed publications for more than 15 years. In 1991 it has faced a re-organisation, with data reliability before that time being significantly lower than today. However, we will come to the discussion on the degree of comprehensiveness of the available data at the end of this paper again. Following the extensive report of the European Commission (Le Floch and Fuchs 2000) on the organisation of research in aquaculture and fisheries in the EU, we will use a similar approach based on publications. After a short introduction to the economics of scientific collaboration, we will introduce the methodology of Social Network Analysis in the context of a bibliographic data set. The approach will be tested on publications from researchers in the EU15, extended by those from Norway and Iceland. We will conclude with a discussion and outlook.

THE ECONOMICS OF SCIENTIFIC COLLABORATION

In the production process of research, actors (scientists) transform inputs into outputs. The input in science can be understood as information, that is, knowledge translated into communicable messages between a set of actors. This means, that a) knowledge can be materialised into oral or written expressions as well as into information stored in a researcher, and b) knowledge needs to be transformed to information. Otherwise, a recipient would not be able to make use of it or more precisely: it would not be tradable (Callon 2002).

Information is in fact tradable very easily. At least, once it has been made public. Information is characterised by distinct attributes. There exists non-rivalry in consumption, i.e. it can be consumed by more than one person without losing its valuable content and at the same time it is possible to exclude other people from using it. As Thomas Jefferson put it the 19th century: “if nature has made any one thing less susceptible than all others of exclusive property, it is the action of the thinking power called idea, which an individual may exclusively possess as long as he keeps it to himself; but the moment it is divulged, it forces itself into the possession of every one, and the receiver cannot dispossess himself of it. Its peculiar character, too, is that no one possesses the less, because every other possesses the whole of it” (cited in Stephan 1996). Another specific characteristic is the high economies of scale, that is, the first output unit produced is by far the most expensive, and the production costs of the second can be assumed to be negligible (equate the material costs).

Knowing the economic properties of information, and knowing that it is the output of the economic activity ‘science’, what remains to answer are the incentives scientists have to share their output with the rest of the scientific community. In the absence of additional rules, the market will fail to provide the socially desirable amount of public goods. Science as a market for the public good ‘information’ has created rules that encourage the production of information. It is the reward structure within the scientific community that helps to overcome these incentive problems. The priority of discovery, formulated by Robert Merton in several articles since the 1950s, explains the mechanism of being rewarded for being first in the communication of new research results. The scientist is rewarded for the discovery by receiving the intellectual property rights for the new idea. Following Stephan (1996), there is a hierarchy of rewards in the scientific community depending on the importance seen in the findings. The possible rewards are eponymy, scientific prizes, membership in elitist societies, and publications. The last is considered a weaker expression of reward, but the most widespread. However, within in the last category, several measures have been established to distinguish the perceived quality. Within these measures the citation count is certainly the most

famous, but also criticised increasingly. The most doubt is associated with the informational value of comparability between disciplines, as citation habits differ widely. Moreover, there is no distinction between positive and negative citation, that is, citation to state disagreement with the cited publication.

Although considered a rather weak expression of reward, scientific publications inherit another characteristic of the scientific community which is expressed most strongly by this communication channel. Most research collaborations are made public by co-authorships on published papers. Co-authorships are considered a strong expression of scientific collaboration as for most co-authorship intensive common work is assumed between the publishing partners. However, some of the criticism on citations about the difficulties of comparison between disciplines holds for this measure as well. The incentives for collaboration in the first place are the same for all scientific disciplines, but some are being slightly more or less emphasised. The general tendency to form collaborations has four major reasons. (1) Specialisation of the disciplines. A single researcher cannot cover all strains even of one discipline. Moreover, multidisciplinary is becoming more important. (2) Differentiation of the disciplines. Most disciplines enlarge their research beyond the core areas. (3) Regional dispersion. Working in an international environment, being tied to different stakeholders, donors, and other sources of funding creates incentives or the need to bridge large geographical distances which is beyond the reach of single researchers. (4) Economies of scale. Especially in the natural sciences, large experimental equipment becomes expensive very quickly. Collaborating with other disciplines or other organisational units within the own field helps making use of economies of scale.

A more sociological perspective would enlarge this list by further reasons. The network effect of being tied in collegial partnership to the impersonalised ‘hot-spots’ of the research field or becoming a structural hole himself, that is, the bridging actor between two research streams, can be measured by means of statistics of graph theory, forming Social Network Analysis. And the position in a network can be valuable, even in economic terms. Therefore, we will discuss this approach more distinctly in the following.

SOCIAL NETWORK ANALYSIS

Exchange of information in science is more than a simple transaction. Ziman argues “the nature of the knowledge produced by this system is closely bound up with its social structure” (Ziman 2002). This idea can be transformed into a social network model, if we consider the knowledge to be produced by individual actors rather than by “a system”, but where the actors are in turn embedded in a specific social structure. The organisation of research, the process of generating knowledge and the process of the diffusion of knowledge in scientific communities have a long history in the social and behavioural sciences.

A social network model measures the relationship between social entities like researchers exchanging information and publishing their scientific output as papers in journals, working papers or conference proceedings. The social network analysis enables research to identify regular patterns within the social group under observation which are referred to as structural identities of this relation. Following Wasserman and Faust (1994) the distinctions that characterise social network analysis in comparison to other relational concepts are the interdependence rather than the independence of actors, the linkages that are a channel for transactions between the actors (e.g. information or reputation), the embedding of actors into a social network of constraints and opportunities for the individual and the conceptualisation of pertinent social structures (economic, political and social relations).

From the network perspective, the linkages between actors can be characterised by any relationship like group membership, kinship or flow of resources. However, it is very important to note, that relations are always measured on a pair of actors, connected by a linkage. The pair is the basic unit under study. The analysis of relationships between actors can include attributes of the individual actor like race, sex, country of origin, or education. The relational tie of a pair of actors always comes first in the collection of the structural identities of the network. The term “social network” refers to a collection of people, each of them being connected to one or more others. Using measurements of social network analysis (descriptive and statistical), one is enabled to identify the strength of influence an individual actor has in the particular social structure.

In the past, many networks have been analysed on the basis of data collected in interviews, e.g. as so called ego-centric networks with actors being asked to name other people they feel acquainted with. Thus, most data sets did not contain more than a hundred actors. With the development of data processing facilities, analytic tools in social network analysis and the World Wide Web as an extensive source of information, social network studies are now workable for large data sets and complex analytic tasks. However, one needs to distinguish between data sets that describe loose social relationships like the interactions in the World Wide Web itself (Albert et al. 2000), and more “real” social relations like actors being associated to each other by the common membership in clubs and associations. In the so called “affiliation networks” the actors have a strong social relationship, and the data set is reliable by the assignment of individual actors as members of such organisations in cold print on membership lists (Newman 2001). An even more precise network is the network of scientific collaboration in co-authorships on published papers. In most cases, it can be assumed, that the common output of scientific interaction in the form of a joint publication is the expression of researchers working closely together. Although being increasingly geographically separated, they share the attribute of knowing each other on a face-to-face basis, at least having met each other in person at the initial contact.

Recently, there has been a growing interest in the analysis of scientific collaboration. First approaches have mapped the flow of information through science within and between disciplines by analysing the citation pattern in publications. This has a long tradition in Bibliometrics (a sub discipline of information science dealing with publication and citation patterns in science). As mentioned above, the intensity of relations in co-authorships has attracted more attention to these approaches and several studies have been conducted on scientific collaboration in various disciplines. So what can be expected when inquiring the research network of aquaculture and fisheries publications? Applying the concept of social networks on the organisation of aquaculture and fisheries research is a challenging task. First, methodologically. The available data sets offer an excellent basis for descriptive and high-numerical statistical analysis, and they do not extend a reasonable size. Thus, a detailed analysis of the attributes of individual researchers is still possible. Second, in comparison to agricultural research, fisheries production and fisheries research undergo an immense development process, shifting the long-term perspective of world fish supply more and more towards sustainable aquaculture production. It is a blue revolution after the green revolution thousands of years ago. The intensity of research on this topic has been volatile within the last decades. The organisation behind the research and development of aquaculture and sustainable fisheries production systems can be expected to have developed accordingly. We will propose a social network model of research organisation that can be applied to the European network of aquaculture and fisheries publications.

A social network can be represented in different ways. In the graph theoretic notation the network is represented by a graph, which consists of nodes and lines. Let $N = \{n_1, n_2, \dots, n_g\}$ denote a set of g actors. They represent the individual researchers. The set of actors N is also named “mode”, that is a distinct set of entities on which structural variables are measured. They are called one-mode networks. All actors belong to one set. Very generally, we can further assume that each actor in N relates to every other actor therein and that the relation is binary-coded: n_i relates to n_j or does not. If a link exists, thus, if $n_{ij} = 1$, the ordered pair is an element of a collection of pairs, denoted as L . If an ordered pair is an element of L , then the first actor relates to the second in this relation (Wasserman and Faust 1994). A graph consists of a set of nodes N that are connected by a set of lines L and can be described by the two sets (N, L) . The symbol G denotes the graph. The simplest possible network can be represented by the algebraic structure $S = \langle N, L \rangle$.

As the co-authorship relation is an affiliation network, a modification has to be made to general social networks. In this particular case, a second mode exists. A second set of actors in a two-mode network can represent e.g. an event, the actors participate in or an organisation, they are members of. In our case, it represents the publication, the authors have published jointly. We denote the second mode by $M = \{m_1, m_2, \dots, m_h\}$. The corresponding graph to a two-mode network is called a *bipartite* graph, as lines connect only nodes from one set to another, but not within the sets. Another distinction to general social networks is that affiliation networks contain information on collections of actors larger than pairs, assuming that social events usually are attended by more than two people. And finally, the relationship between the first and the second mode can be considered as complementary. That is, the actors can be connected to one another by their affiliation with organisations and at the same time the organisations can be connected to one another by the actors who are members of them. It is thus called a co-occurrence relation (Wasserman and Faust 1994). For analytical purposes, two-mode networks can be transformed into one-mode networks, with the nodes of the second set (articles) becoming elements of the first set (authors). Whenever two papers share an author in the two-mode network, there is a link between them in the one-mode network. In a two-mode network the interconnectivity of an actor with one or more organisations is represented by loops. A loop is a line that connects an actor to itself, e.g. it represents the number of co-authors on a paper. Whenever an author has participated in writing more than one paper, he is connected to the other papers by multiple lines, which will be labelled by his name in a two-mode network. These multiple lines can be replaced by a valued single line, indicating by the value the number of former single lines of an author. To this transformed and simplified two-mode network, the standard techniques of one-mode networks can be applied, although there remain some differences one has to consider when analysing results from such networks (Nooy et al. 2005).

The diameter of a network is the length of the largest geodesic between any pair of nodes where the geodesic measures the shortest distance between any pair of nodes. The diameter thus quantifies the distance between the most distant two nodes in a graph. The density of a network gives back the proportion of possible lines actually present in the graph. It is the ratio of the number of lines present to the maximum possible. It ranges from 0 to 1. The density of a graph is the average proportion incident with the nodes in the graph (Wasserman and Faust 1994). To measure the position of an actor in a network, that is, its position to other actors with regard to the flow of information, Social Network Analysis uses the concept of centrality.

The betweenness centrality defines an actor to be central if it lies between other actors on their geodesics, implying that to have a large betweenness centrality, the actor must be between many of the actors via their geodesics (Wasserman and Faust 1994). This measure can also be

applied to a network and is the named betweenness centralization. It is the variation in the betweenness centrality of nodes divided by the maximum variation in betweenness centrality scores possible in a network of the same size (Nooy, Mrvar and Batagelj 2005).

RESULTS FOR EU15 PLUS NORWAY AND ICELAND

The most common database for peer-reviewed publications is the Thomson Scientific ISI Web of Science. The Science Citation Index (SCI) Expanded that is produced by the ISI provides an extensive database on journal articles as well as on proceedings, reviews and letters. The SCI Expanded is a multidisciplinary index, including some 5900 journals of the sciences. We collected data on the world total publications on aquaculture and fisheries for the years 1990 to 2005, and extracted from that the publications of authors coming from the countries of the EU15, Iceland and Norway (in the following referred to as European papers). For a general comparison by Bibliometric measures, a third data set on publications from the USA and Canada has been included. For data manipulation purposes the files, originally exported from the ISI, were integrated into a SQL database. The country of origin as well as the institutional affiliation is therein identifiable by the corresponding address information. A static-comparative analysis is applied to three time periods, covering five years each in the period between 1990 and 2005.

In general, the development over time is very similar in all three networks. All regions show an increase in the number of authors per paper, indicating a tendency to more collaboration on scientific publications. However, the number of publications has increased more than fivefold in the two European data sets, whereas the number of USA/Canada publications increased not even threefold over the same period (see Table 1). These findings also apply to the growth rates for the number of authors.

Table 1 here

Some descriptive analysis on the social network properties of the Bibliometric data sets has been applied. The diameter measures the distance between the most distant two nodes in the graph. It gives important information on the proximity of researchers, measured by their co-authorship relations. How well do researchers know each other, how many common colleagues do they share? This is important for the diffusion of knowledge. For the three compared networks, there is no common development. The diameter increases in the EU15 network in all consecutive time periods. Thus, the network is growing, but the distance of researchers is also growing. In the EU15 plus network, the diameter increases and decreases again, indicating a better integration of all actors in the growing network. In the US network, the diameter increases and stabilises on a high level.

The density of a network measures the ratio of lines present to the maximum possible number of lines in the network, and it decreases in all three networks over the observed time period. This is in accordance with findings in other publication networks, indicating a non-normal distribution of nodal degrees. Some authors tend to integrate more intensively than others, writing more papers than others. In many large complex networks, there is a power-law degree distribution.

To measure the position of an actor in the network, Social Network Analysis uses different concepts of centrality. With regard to the importance of an actor in the flow of information, betweenness centrality is more precise than other centrality concepts. By definition, an actor is central if it lies between other actors on their geodesics, implying that to have a large betweenness centrality, the actor must be between many of the actors via their geodesics (Wasserman and Faust 1994). On the network level, centrality is measured as the variation in the betweenness centrality of nodes divided by the maximum variation in betweenness centrality scores possible in a network of the same size (Nooy, Mrvar and Batagelj 2005). This is called betweenness centralisation. In all three networks, higher values of betweenness centralisation are indicating an increasing variation of betweenness centrality scores of all actors in the network. Thus, as some actors receive higher scores than others, the number of actors with a central position in the network increases, or some actors succeed in increasing their centrality even more. With regard to the three different networks, it can be stated that betweenness centralization indicates a larger variance in centrality scores especially in the last two observation periods for the two European networks of EU15 and EU15 plus, whereas the USA network shows a less high variance in centrality scores.

The second Social Network Analysis approach analyses the collaboration pattern of the EU15 and EU15 plus publications within the EU, with non-EU, and with the USA and Canada on the country level (see Table 2). In the EU15, a growing share is devoted to within-EU collaborations. Only in the last observation period between 2001 and 2005 this share is slightly decreasing. However, after a strong increase in the share of USA and Canada collaborations within the group of non-EU collaborations, it has seen a significant decrease in the last observation period. Thus, the co-authorship relations to non-EU and non USA/Canada research partners has increased. This development is the same for the EU15 plus group including Norway and Iceland, though the share of non-EU collaborations is even bigger in that group. However, in this group we do not see such a clear development of increasing within-EU collaborations, but rather a decreasing tendency from a very high starting level, with a recovery to a slightly lower level than in the first observation period.

Table 2 here

Further analysis on the country level of the EU15 plus publishing countries is shown graphically (see Figures 1A-C). These three networks show the development of within-EU15 plus collaborations, aggregated to the country level, over three time periods since 1990. The width of the lines represents the intensity of co-authorship relations between authors of the related countries. It is an undirected network, that is, the co-authorship relation is assumed to be reciprocal for all connected researchers. The nodes are labelled by the country name. The most obvious result is strong research collaboration between Scotland and England, but also between England and France. Another strong collaboration pattern can be found between the Scandinavian countries of Denmark, Sweden and Norway.

Figures 1A-C here

In the second time period ranging from 1996 to 2000 the network as such is characterised by much more links between the countries. The strong relationship between Scotland and England continues to exist, but the close collaboration between England and France seems to have been

substituted by a much more diversified collaboration of France and England with the rest of the European partners, respectively. Among others, it is noteworthy that Portugal has become a well integrated research collaborator in the European network, collaborating most intensively with Scotland. In the last time period until 2005, the research collaboration on aquaculture and fisheries has intensified among all European countries. Here it is noteworthy to point out Norway, which receives the highest score of betweenness centrality.

SUMMARY AND OUTLOOK

This study uses Bibliometrics and Social Network Analysis for analysing the collaboration pattern of aquaculture and fisheries research in the EU15, Norway and Iceland. The data are derived from the ISI Web of Science for three time periods of five years each between 1990 and 2005.

Analysing the development of co-authored publications within the European research area on the country level shows a network that is increasingly integrated. By means of graphic visualisation, a growing network with countries increasingly integrated can be identified. Further research on this development is expected to provide a valuable assessment of the impact European Framework Programmes (FP) had in enhancing aquaculture and fisheries research. All Bibliometric descriptors and the social network statistics applied point in the direction, that the goals of the FPs related to stimulating European research collaboration have been achieved. With regard to the growing share of non-European research collaborations, it can be assumed, that research follows to some extent the regional hot-spots of fisheries and aquaculture production. At the same time, we were able to use Social Network Analysis for providing information on the rise and fall of research institutions and universities in aquaculture and fisheries research (see Appendix A-C).

However, the data basis may certainly be subject of a viable discussion. As the second approach to measure scientific performance by analysing citation paths of publications, it is questionable if the indicator of peer-reviewed publications, indexed in the ISI Web of Science, is (a) comprehensive enough in the journals indexed, (b) capturing the publication channel with the highest scientific impact, and (c) covering all publication languages proportionally to their appearance in the scientific community.

For further analysis, the concept of preferential attachment provides a promising tool to explain, why central authors, once they are detected in the network, are able to strengthen their position by attracting more co-authors in relation to other scientists. This concept explains why the successful stay successful or improve their position, but it does not give any explanation of the factors influencing the decision to accept or to deny the co-authorship of a scientist seeking to attach to the famous colleague. What social criteria are the basis for acceptance or deny of collaboration? We suggest extending the affiliation model of scientific publications by further characteristics of the individual actors. Such characteristics will be affiliations to scientific organisations and associations. In this context, we suggest to apply the concept of interlocking networks to scientific organisations and their members. This concept has first been applied to interlocking directorates to measure the importance of simultaneous membership in directorates of large business companies (Stockman, Ziegler and Scott 1985). More on the scientist's level, the integration of attributes related to the individual career of a scientist will further extend the social network model. In particular, aspects like the origin of the degree (university), the origin of the doctoral thesis (university or tutor) and the current institution.

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APPENDIX A

Top Institutions and Universities by number of publications in ISI Web of Science, 1990-1995

Country	Institution	No. of Publications	in % of all publications
AUSTRIA	INT INST APPL SYST ANAL, LAXE	1	0.19%
AUSTRIA	SALZBURG UNIV	1	0.19%
BELGIUM	INST NAT CONSERVAT	1	0.19%
BELGIUM	STATE UNIV GHENT	3	0.58%
DENMARK	DANISH INST FISHERIES & MARINE RESEARCH	3	0.58%
DENMARK	AALBORG UNIV	1	0.19%
ENGLAND	MAFF, DIRECTORATE FISHERIES RES	19	3.67%
ENGLAND	UNIV NEWCASTLE UPON TYNE	4	0.77%
ENGLAND	UNIV HULL	4	0.77%
FRANCE	IFREMER	15	2.90%
FRANCE	UNIV MONTPELLIER	6	1.16%
GERMANY	INST MEERESKUNDE,KIEL	3	0.58%
GERMANY	RUHR UNIV BOCHUM	3	0.58%
GREECE	NATL CTR MARINE RES	4	0.77%
GREECE	ARISTOTELIAN UNIV SALONIKA	1	0.19%
ICELAND	MINIST FOREIGN AFFAIRS	1	0.19%
ICELAND	UNIV ICELAND	2	0.39%
IRELAND	CENT FISHERIES BOARD, DUBLIN	1	0.19%
IRELAND	UNIV DUBLIN TRINITY COLLEGE, DUBLIN	4	0.77%
ITALY	FAO, DEPT FISHERIES	17	3.28%
ITALY	CNR,IST TECNOL PESCA & PESCATO	1	0.19%
ITALY	UNIV ROMA	4	0.77%
NETHERLANDS	NETHERLANDS INST FISHERIES RES	7	1.35%
NETHERLANDS	AGR UNIV WAGENINGEN,	13	2.51%
NORTH IRELAND	DEPT AGR NO IRELAND	5	0.97%
NORTH IRELAND	UNIV ULSTER	2	0.39%
NORWAY	NORWEGIAN INST NAT RES, TRONDHEIM	9	1.74%
NORWAY	UNIV BERGEN,DEPT FISHERIES & MARINE BIOL	13	2.51%
PORTUGAL	INST PORTUGUES INVEST MARITIMA	2	0.39%
PORTUGAL	UNIV ACORES	2	0.39%
PORTUGAL	UNIV ALGARVE	2	0.39%
SCOTLAND	SCOTTISH OFF AGR & FISHERIES DEPT	7	1.35%
SCOTLAND	UNIV STIRLING,INST AQUACULTURE	9	1.74%
SPAIN	CSIC	7	1.35%
SPAIN	UNIV SANTIAGO	6	1.16%
SWEDEN	SWEDISH ENVIRONM RES INST	1	0.19%
SWEDEN	UNIV STOCKHOLM	7	1.35%
WALES	NATL RIVERS AUTHOR	3	0.58%
WALES	UNIV COLL SWANSEA,SCH BIOL SCI,SINGLETON	5	0.97%

APPENDIX B

Top Institutions and Universities by number of publications in ISI Web of Science, 1996-2000

Country	Institution	No. of Publications	in % of all publications
AUSTRIA	Austrian Acad Sci	3	0.19%
AUSTRIA	Salzburg Univ	7	0.44%
BELGIUM	Musee Royal Afrique Cent (MRAC)	4	0.25%
BELGIUM	Univ Liege	18	1.12%
DENMARK	Danish Inst Fisheries & Marine Research	28	1.75%
DENMARK	Univ Copenhagen	10	0.62%
ENGLAND	CEFAS, LOWESTOFT	29	1.81%
ENGLAND	Univ London	29	1.81%
FRANCE	IFREMER	48	2.99%
FRANCE	Univ Montpellier	20	1.25%
GERMANY	Inst Freshwater Ecol & Inland Fisheries	11	0.69%
GERMANY	Univ Hamburg	9	0.56%
GREECE	Inst Marine Biol Crete	12	0.75%
GREECE	ARISTOTELIAN UNIV THESSALONIKI	4	0.25%
GREECE	Univ Thessaly	4	0.25%
ICELAND	Marine Res Inst	11	0.69%
ICELAND	Univ Iceland	8	0.50%
IRELAND	Fisheries Res Ctr	8	0.50%
IRELAND	Natl Univ Ireland	11	0.69%
ITALY	FAO, DEPT FISHERIES	23	1.43%
ITALY	CNR	10	0.62%
ITALY	Univ Roma Tor Vergata	9	0.56%
NETHERLANDS	Netherlands Inst Fisheries Res	16	1.00%
NETHERLANDS	Wageningen Univ Agr	14	0.87%
NORTH IRELAND	Dept Agr No Ireland	6	0.37%
NORTH IRELAND	Queens Univ Belfast	5	0.31%
NORWAY	Inst Marine Res, BERGEN	33	2.06%
NORWAY	Univ Bergen	25	1.56%
PORTUGAL	Inst Super Psicol Aplicada	9	0.56%
PORTUGAL	Univ Algarve	12	0.75%
SCOTLAND	Dunstaffnage Marine Res Lab	12	0.75%
SCOTLAND	Univ Glasgow	31	1.93%
SPAIN	CSIC	37	2.31%
SPAIN	Univ Barcelona	15	0.94%
SWEDEN	Natl Board Fisheries	9	0.56%
SWEDEN	UNIV STOCKHOLM	21	1.31%
WALES	CEFAS	5	0.31%
WALES	Univ Wales, Cardiff	12	0.75%

APPENDIX C

Top Institutions and Universities by number of publications in ISI Web of Science, 2001-2005

Country	Institution	No. of Publications	in % of all publications
AUSTRIA	Int Inst Appl Syst Anal	2	0.08%
AUSTRIA	Salzburg Univ	5	0.21%
AUSTRIA	Graz Univ	5	0.21%
BELGIUM	Africa Museum	3	0.12%
BELGIUM	State Univ Ghent	18	0.74%
DENMARK	Danish Inst Fisheries & Marine Research	48	1.98%
DENMARK	Univ Copenhagen	11	0.45%
ENGLAND	CEFAS, LOWESTOFT	67	2.77%
ENGLAND	Univ London	35	1.45%
FRANCE	IFREMER	73	3.01%
FRANCE	Univ Montpellier	12	0.50%
GERMANY	Leibniz Inst Freshwater Ecol & Inland Fisheries	33	1.36%
GERMANY	Univ Hamburg	8	0.33%
GREECE	Hellen Ctr Marine Res	13	0.54%
GREECE	Aristotelian Univ Thessaloniki	14	0.58%
ICELAND	Marine Res Inst	7	0.29%
ICELAND	Univ Iceland	5	0.21%
IRELAND	n.a.	n.a.	-
IRELAND	Natl Univ Ireland Univ Coll Cork	22	0.91%
ITALY	FAO, DEPT FISHERIES	19	0.78%
ITALY	CNR	16	0.66%
ITALY	Univ Lecce	12	0.50%
NETHERLANDS	Netherlands Inst Fisheries Res	11	0.45%
NETHERLANDS	Univ Wageningen & Res Ctr	36	1.49%
NORTH IRELAND	Dept Agr & Rural Dev No Ireland (DARDI)	3	0.12%
NORTH IRELAND	Queens Univ Belfast	8	0.33%
NORWAY	Inst Marine Res, BERGEN	42	1.73%
NORWAY	Univ Tromso	26	1.07%
Portugal	IPIMAR	15	0.62%
Portugal	Univ Algarve	27	1.11%
SCOTLAND	Fisheries Res Serv (FRS)	44	1.82%
SCOTLAND	UNIV STIRLING, INST AQUACULTURE	32	1.32%
SPAIN	CSIC	64	2.64%
SPAIN	Univ Murcia	12	0.50%
SPAIN	Univ Santiago de Compostela	12	0.50%
SWEDEN	Natl Board Fisheries	9	0.37%
SWEDEN	UNIV STOCKHOLM	39	1.61%
WALES	Environm Agcy	3	0.12%
WALES	Univ Wales, Cardiff	26	1.07%

Table 1: Data set and descriptive statistics

	EU 15			EU 15 plus Norway and Iceland			USA		
	1990-1995	1996-2000	2001-2005	1990-1996	1996-2001	2001-2006	1990-1995	1996-2000	2001-2005
No. of papers	498	1636	2620	559	1826	2846	702	1393	2066
No. of authors	1077	3706	6447	1199	4040	6884	1404	3255	5014
No. of edges	1442	6533	13156	1609	7343	14505	1649	4074	6863
Mean no. of papers per author	0.46	0.44	0.41	0.47	0.45	0.41	0.50	0.43	0.41
Mean no. of authors per paper	2.16	2.27	2.46	2.14	2.21	2.42	2.00	2.34	2.43
Density	0.00275	0.00117	0.00096	0.00260	0.00122	0.00083	0.00219	0.00149	0.00096
Diameter	4	17	30	4	33	23	7	23	24
Betweenness Centrality	0.00013	0.00121	0.04110	0.00009	0.00927	0.03175	0.00035	0.00209	0.01993

Table 2: Co-Authorship Relations of EU 15 and EU 15 plus Countries

	1990-1995	1996-2000	2001-2005
EU 15 + Collab.	912	5248	10994
EU 15	650	4265	8875
EU 15 in %	71.27%	81.27%	80.73%
Non-EU in %	28.73%	18.73%	19.27%
USA/Canada	6.47%	7.30%	6.06%
EU 15 plus + Collab.	1014	5928	12229
EU 15 plus	900	4468	10180
EU15 plus in %	88.76%	75.37%	83.24%
Non-EU in %	11.24%	24.63%	16.76%
USA/Canada	6.61%	8.10%	6.37%

Figure 1A: EU 15 plus Norway and Iceland Network of Publications, 1990-1995

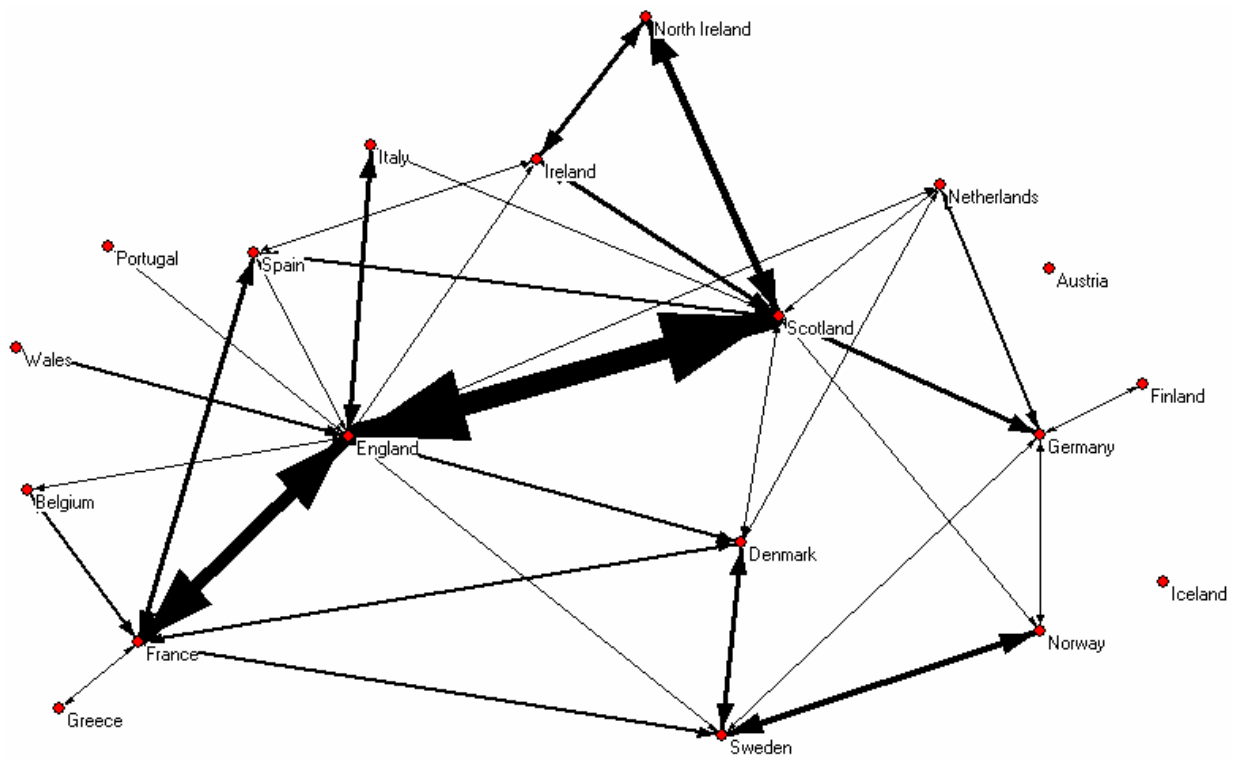


Figure 1B: EU 15 plus Norway and Iceland Network of Publications, 1996-2000

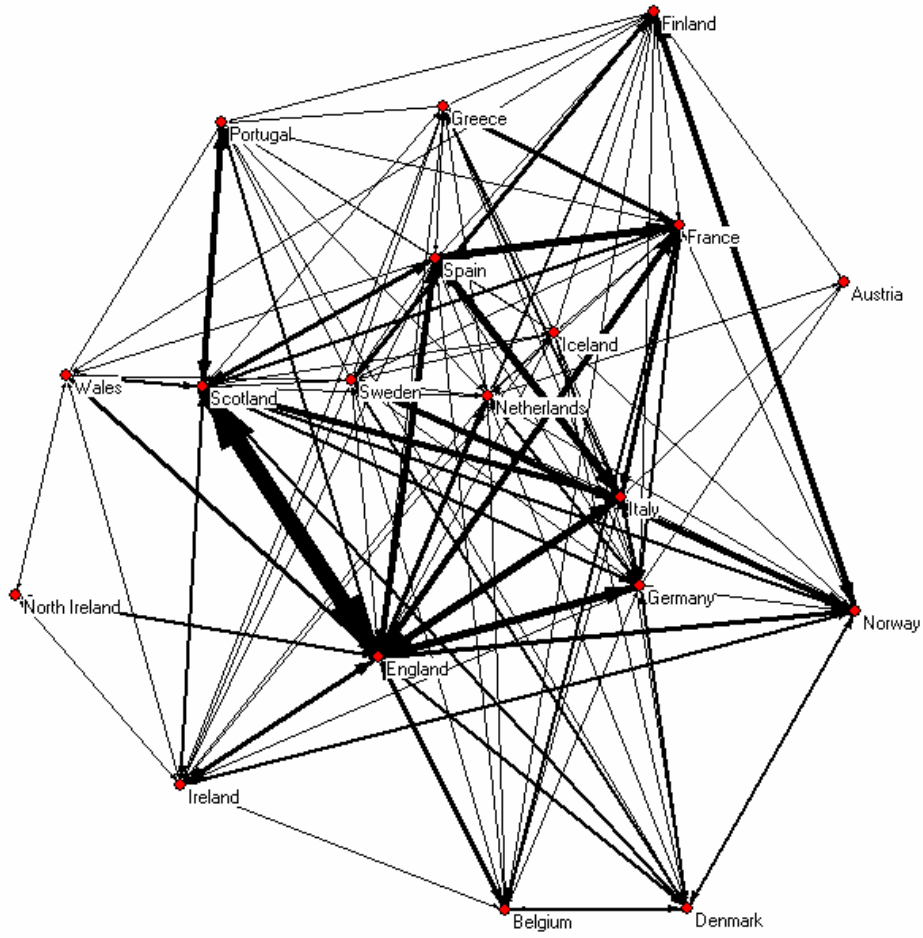


Figure 1C: EU 15 plus Norway and Iceland Network of Publications, 2001-2005

