Ocean Science & Technology research across the countries: A global scenario

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In this paper attempt has been made to unfold the intellectual base in ocean science and technology. The articles appeared in *Science Citation Index* (SCI) under Oceanography in the year 2000 were analyzed to decipher the scientist to scientist, organization to organization and country to country network structures. The causal linkages between the knowledge productivity function and the socio-economic imperatives of knowledge production units were studied.

Introduction

Ocean has always been an inseparable component of human existence. From the origin of life right up to its continuous sustenance, ocean has always played a strong role in shaping the destiny of the mother earth by exerting a profound influence on its resources and environment. Most of the earth surface, as large as 70%, is covered by ocean. In spite of its ubiquitous presence it has always remained a mystery to the mankind, waiting to be understood and fully explored. It is estimated that more than half the world's population live within 60 km of the shoreline, and this could rise to three-quarters by the year 2020 (UNCED, 1992).

Rapid growth of population, utilization of resources to meet the requirement of the changing lifestyle which demands rapid utilization of limited resources of lands, the attention is turning towards a comparatively less explored reservoir of resources – The Ocean. In this work attempts have been made to understand the intellectual structure of Ocean Science and Technology by unfolding the country to country, institute to institute and at unit level scientist to scientist network structure, and its relational linkages with socio-economic imperatives of the countries.

Received August 25, 2003

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0138–9130/2004/US \$ 20.00

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Methodology

While there may be several indicators to study science & technology dynamics, research publications in peer-reviewed scientific journals are widely regarded as one of the most important indicators. The journals that make its way to *Science Citation Index* (SCI) database of Institute of Scientific Information, Philadelphia pass through a standard and uniform quality check making the data reliable for comparison and structural analysis.

4008 articles from 35 journals for the year 2000, under oceanography category, were downloaded from SCI (CD-ROM version). Oceanography category also includes journal of Ocean Engineering specialty. Articles covered in these journals, commonly referred to as international 'mainstream research', provide a representative picture of the structure of knowledge in the subject specialty. Author names, organization names and country names were isolated separately and rank ordered (PERSSON, 2002). The most productive scientists were chosen to form co-occurrence matrices to which a multidimensional scaling algorithm (a systat sub-routine) was applied to produce the network maps. In case of countries and organizations also the same methodology was adopted. The size of the circles is proportional to the size of the attributes, and the lines between the attributes indicate presence of collaboration links while the width reveals the size of the frequency.

Results and discussion

Oceanography is a multifaceted discipline. Ocean is a single mass of water body encompassing the entire earth. From time immemorial ocean has been used for joint ventures like trade and commerce, science is no exception. Spirit of collaboration is natural in this discipline. In addition to its multidisciplinarity and its reflexivity, the scientific enterprise is organized at various levels of aggregation (LEYDESDORFF, 2001) and under certain conditions it is possible at some of these levels to convert resources and results into the one another (LATOUR & WOOLGAR, 1979). Three kind of linkages were explored; these maps are the representation of knowledge networking at individual level, organizational level culminating into country level.

The communication pattern between the production units reflects the knowledge structure of the subject specialty. The social and economic conditions are important determinants for the research activity structure of the countries. The scientific activities of the countries are the reflection of their intellectual and social imperatives.

Some international events in the field may be marked as the booster for the rising level of activities in Ocean sector across the world, apart from the fact that some countries enjoy a rich maritime history, and naturally they become a strong activity center. Challenger expedition initiated by Royal Society of London in 1872 to study the ‘condition of deep sea throughout all of the great basins’ considered to be the first organized scientific expeditions in the world. The United Nations Convention of the Law of the Sea (UNCLOS), adopted in the year 1982, played an important role in establishing a legal regime of the Oceans – coastal states and islands, led to the spurt of activities in Ocean sector in the world. 1998 was celebrated as the International Year of the Ocean’ signifying its growing importance and imperative need to improve the understanding of the Ocean and its various inter-related processes. Legal Continental Shelf (LCS) program, under UNCLOS, is involved with the measuring the extent of continental shelf of the nations for outlining the sovereign boundaries of the nations. The geopolitical importance of the issues may be an important motivating factor for increasing number of international programs with multinational commitments.

Oceanic processes and climate dynamics are intimately interwined. Understanding the dynamics of climate change and its predictability could be of enormous economic and societal importance – knowing a season or more ahead, how much rainfall is likely to occur, can influence the decision on which crop to plant, such knowledge can affect farming, insurance, energy distribution and myriad other activities over large regions. A better understanding of ocean circulation and the feedback mechanism between the ocean and atmosphere is crucial to improving our ability to forecast climate. The World Ocean Circulation Experiment (WOCE), an unique program with participation of around 30 nations under the leadership of USA generated high quality data led to new insights into how the ocean operates as well as evidence for long term variations and changes. Main participating institutes like National Aeronautics and Space Administration (NASA) & National Oceanic and Atmospheric Administration (NOAA) of US occupying leading positions in the list of most productive institutes in Ocean Science & Technology. The networks maps (Figures 2 and 3) are showing large clusters working on oceanic processes and climate change. In fact, the leading position of USA corroborates the fact that it has become an active center of origin and coordinating point of many important international programs.

In modern day research economic conditions play a major role. Oceanography is no exception. It is a point to note that all the top five countries in terms of productivity are members of the elite G-5 group (Table 2). While all the top 25 countries are members of the Intergovernmental Oceanographic Commission (IOC) of United Nations, an active forum dealing with ocean and ocean related issues, showing their interest and commitments in Ocean sector.

Country to country network

Cutting edge science in many fields increasingly involves a broad range of knowledge perspectives and techniques that extend beyond a given discipline or institution. In oceanography research questions are mostly multidisciplinary covering wide range of environmental regimes cutting across geographical boundaries of the countries. Collaboration between the countries widens the scope to address the issues.

The countries were rank ordered according to the scientific output. Top 25 countries were chosen to produce the network structure (Table 2). USA is found to be leading the list with around 50% of world share in knowledge production followed by UK, Germany, France, Japan and Canada. The countries at the core of the cluster are members of elite G-5 group, indicating their positional advantage in the network. Broadly, in the network map the countries are arranged in 3 concentric circles, the center is occupied by the G-5 countries followed by Australia, Canada, Russia, Netherlands etc., while the outer ring is dominated mostly by developing countries like India, Brazil, etc. (Figure 1).

Figure 1. Country collaboration map (Co-authorship)

Network Analysis. Apart from giving visibility to the scientists, collaboration provides flexibility to the countries to address multidisciplinary and multispatial issues that oceanography demands. Countries with more cooperation links, as in the case of the USA, are already acknowledged as the site of advanced research in the field and many of the links are forged by less advanced countries seeking to tap their expertise. Besides, the collaborating countries are better placed to address research questions as they can enjoy the benefit of having the power of collective wisdom and less dependent on any particular country, hence they are supposed to be more influential in the field.

The data on cooperation links were tabulated in the form of valued adjacency matrix where

$$C = | C_{ij} | .$$

Where C_{ij} , denotes the number of cooperation links between country i and county j . Obviously

$$C_{ii} = 0 .$$

Scientific cooperation between the countries is a function of scientific size of the countries, while the pattern is not. The pattern of cooperation must be viewed without the confounding effects due to size. For controlling the effect of the size, a special index – Salton Index – was computed by using the following formulae (NAGPAUL, 2001):

$$\text{Salton Index} = \frac{C_{ij}}{\sqrt{\sum_i \sum_j}} .$$

The entries in the matrix indicate the strength of cooperation links between pairs of countries. Since the links are bi-directional, the matrix is symmetric. 202 cooperation links (67.33%) are observed out of 300 $[n(n-1)/2]$ expected links. Certain countries have strong links with many other countries; their network of cooperation is quite extensive. In other words, they occupy a central position in the international network of science. In this study Bonacich Power Centrality is used to indicate the position of the country in the network. It uses iterative weighting to assign higher scores to actors who have stronger ties to more central actors.

Table 1. Network Centrality of top 25 countries

Rank	Country	Bonacich Power
1	USA	2.390
2	Germany	1.480
3	UK	1.470
4	France	1.320
5	Canada	0.920
6	Japan	0.910
7	Russia	0.880
8	Netherlands	0.860
9	Australia	0.820
10	Italy	0.770
11	Norway	0.750
12	Sweden	0.750
13	Denmark	0.640
14	Finland	0.560
15	Switzerland	0.550
16	Greece	0.530
17	Belgium	0.520
18	Peoples R China	0.520
19	Spain	0.510
20	South Africa	0.430
21	New Zealand	0.410
22	Mexico	0.400
23	India	0.290
24	Taiwan	0.260
25	Brazil	0.240

Not surprisingly, the centrality list places six G-7 countries on top, Russia being the other country occupying the seventh place.

Country clusters and Institute clusters. The organizations and the countries leading the rank order, are actively pursuing many international projects. Uninterrupted time series data is an essential prerequisite to understand climate change. The Climate & Global change program of National Oceanic and Atmospheric Administration (NOAA) is involved with producing scientifically controlled oceanographic databases. NOAA-AVHRR satellite is a popular satellite collecting ocean data from around the world. Countries having deployed satellites, floating sensors etc. for ocean data collection are

there in the top layer of the list. USA, UK, Japan, France, Canada, Australia and India are working together for an ambitious project of deploying 3000 profiling floats distributed all over the global ocean for continuous collection of data on oceanic parameters across the globe.

S. Levitus leading the list as most referred scientist in the field, is responsible for producing world ocean atlas for different parameters. These atlases are produced under NOAA climate and Global Change program. Levitus data is popular among scientists, as the data set are reliable, and available for a long time series. A well designed policy for oceanographic data (NSF, 1994) could be instrumental in developing well organized programs on ocean data collection, quality check and its storage, making the data reliable for scientific studies.

Apart from being active in the scientific activities, USA, UK, The Netherlands and Germany are producers of many international quality journals (TAPASWI, 1999) which commensurate with the higher level of activities in this subject specialty. Intergovernmental Oceanographic Commission (IOC) under the aegis of United Nations is active in executing multi-institutional and multinational projects. Global Ocean Observing System (GOOS) program is involved in systematic and Scientific Observation of Global Oceans. Joint Global Ocean Flux Studies (JGOFS), Sea Level Monitoring and Modeling (SELMAM), Coral Reef Monitoring (GCRMN) are implemented region wise. Its Regional Seas Program designed to provide impetus to regional interests of the oceanic realm. These international programs have boosted the activities in ocean sector in the participating countries.

Socio-economics of knowledge production. Social condition, economic & political stability of the countries influence the character of knowledge production enterprise. Interplay of various parameters in the self-organizing paradigm provides a character to the production system. The rank order of the coastline of the countries does not follow the productivity profile. Being land locked does not prevent Switzerland to have ocean related interests and make its position to the top layer of the productive countries. In our data set, 85% productivity goes to G-5 countries (USA, UK, France, Germany and Japan), while 94% share is accounted by G-7 countries (G-5 + Canada & Italy). Because the GDP and the productivity are highly unevenly distributed, their logarithms have been used in doing regression analysis. In our data set, the R^2 Value for the GDP (log) vs. productivity is 0.33, while globally, the empirical relationship between the size of the nations economy – its Gross Domestic Product (GDP) and its productivity volume was found to be moderately high (0.50) (NSF 2000). This may corroborates the fact that only higher GDP may not be the only factor to put the countries on the top of the productivity list; it is an expression of a complex social milieu, impregnated its

commitments in wisdom, quality of life and other philosophical imperatives. For some countries productivity (articles/\$ billion GDP) goes in excess of what could be expected based on raw economic size (NSF 2000)(Table 2).

Table 2. Socio-economic parameters of the countries

Rank	Country	Coastline (km)	Literacy (%)	Productivity (no. of articles)	World share (%)	Log of produc- tivity	GDP Purchasing power parity (US \$ billion)	Log of GDP (PPP)	Articles/GDP \$ billion
1	USA	19,924	97	1991	42.11	3.30	8083.0	3.91	0.25
2	UK	12,429	99	429	9.07	2.63	1,242.0	3.09	0.35
3	Germany	2,389	99	383	8.10	2.58	1740.0	3.24	0.22
4	France	3,427	99	360	7.61	2.56	1320.0	3.12	0.27
5	Japan	29,751	99	263	5.56	2.42	3,080.0	3.49	0.09
6	Canada	243,791	97	228	4.82	2.36	658.0	2.82	0.35
7	Russia	37,653	98	202	4.27	2.31	692.0	2.84	0.29
8	Australia	25,760	100	195	4.12	2.29	394.9	2.6	0.49
9	Netherlands	451	99	147	3.11	2.17	343.9	2.54	0.43
10	Italy	7,600	98	125	2.64	2.10	1,240.0	3.09	0.10
11	New Zealand	15,134	99	99	2.09	1.99	63.4	1.8	1.56
12	Spain	4,964	97	88	1.86	1.94	642.4	2.81	0.14
13	Norway	21,925	100	82	1.73	1.91	120.5	2.08	0.68
14	Denmark	7,314	100	69	1.46	1.84	122.5	2.09	0.56
15	Sweden	3,218	99	69	1.46	1.84	176.2	2.25	0.39
16	P. R China	14,500	82	62	1.31	1.79	4250.0	3.63	0.01
17	Switzerland	0 (land locked)	99	56	1.18	1.75	172.4	2.24	0.32
18	Greece	13,676	97	55	1.16	1.75	137.4	2.14	0.40
19	Taiwan	1,566	86	49	1.04	1.69	308.0	2.49	0.16
20	India	7,000	52	48	1.02	1.68	1534.0	3.19	0.03
21	Mexico	9,330	90	45	0.95	1.65	694.3	2.84	0.06
22	Finland	1,126	100	42	0.89	1.62	102.1	2	0.41
23	South Africa	2,798	85	42	0.89	1.61	270.0	2.43	0.16
24	Belgium	66	98	41	0.87	1.61	236.3	2.37	0.17
25	Brazil	7,491	83	41	0.87	1.61	1,040.0	3.02	0.04

Organization to organization network

Thirty-three most productive institutes were selected to produce the network map (Figure 2). NASA (USA) was leading the list followed by Russian Academy of Sciences, NOAA, Woods Hole Institute (USA), University of Washington and University of San Diego.

Figure 2. Institutional collaboration map (Co-authorship)

Table 3. Country affiliations of the most productive institutions

Rank	Institute	Productivity (No. of articles)	Home Country	Rank	Institute	Productivity (No. of articles)	Home Country
1	NASA	276	USA	18	IFREMER	51	France
2	Russian Acad Sci	129	Russia	19	Southampton Oceanog Ctr	50	USA
3	NOAA	124	USA	20	Univ Paris	49	France
4	Woods Hole Oceanog Inst	100	USA	21	Univ Calif Berkeley	49	USA
5	Univ Washington	94	USA	22	Johns Hopkins Univ	48	USA
6	Univ Calif San Diego	93	USA	23	Columbia Univ	46	USA
7	Caltech	88	USA	24	Univ Utrecht	45	Germany
8	Univ Colorado	73	USA	25	Univ Cambridge	43	UK
9	MIT	71	USA	26	Univ Calif Santa Cruz	43	USA
10	USN	67	USA	27	Univ Michigan	43	USA
11	Univ Maryland	67	USA	28	Los Alamos Natl Lab	43	USA
12	US Geol Survey	64	USA	29	Univ Calif Santa Barbara	41	USA
13	Natl Ctr Atmospher Res	63	USA	30	Nagoya Univ	41	Japan
14	Univ Calif Los Angeles	63	USA	31	Princeton Univ	40	USA
15	CNRS	57	France	32	Hokkaido Univ	40	Japan
16	Univ Miami	55	USA	33	Univ Hawaii	40	Japan
17	Univ Tokyo	52	Japan				

Scientist to scientist network

Co-citation analysis is one of the major quantitative techniques in science studies to map the structure and dynamics of scientific research (BRAAM, 1991). By citing two documents in one article an author establishes a co-citation link. Ocean is a multifaceted subject. Co-citation maps reflect subject similarities and disciplinary structures representing the actual cognitive structure as it is perceived by practicing scientists (LEYDESDORFF, 1987). 50 most cited scientist were considered for making the map. Levitus S, Broecker WS, Press WH, Gill AE, Wyrski K were some of the scientists leading the list (Figure 3).

Figure 3. Knowledge cohesion: First author co-citation network

Table 4. Most cited first authors

Rank	No. of citations	Name	Rank	No. of citations	Name
1	148	Levitus S	19	59	Crutzen PJ
2	147	Anon	20	59	Berger WH
3	105	Broecker WS	21	58	Charlson RJ
4	100	Press WH	22	57	Hellerman S
5	97	Gill AE	23	56	Russell CT
6	86	Wyrki K	24	56	Parsons TR
7	81	Demore WB	25	55	Banse K
8	75	WMO	26	54	Eppler RW
9	75	Martin JH	27	53	Berner RA
10	73	Honjo S	28	53	Karl DM
11	72	Mellor GL	29	52	Sverdrup HU
12	70	Pedlosky J	30	52	Kalnay E
13	69	Trenberth KE	31	51	Houghton JT
14	64	Holton JR	32	51	Solomon S
15	62	Gordon AL	33	50	Reid JL
16	61	Wessel P	34	50	Gosling JT
17	60	Andreae MO	35	50	Jacob DJ
18	59	Singh HB	36	50	Bryan K

Conclusion

The present study is a temporal snapshot of the activity dynamics of the knowledge enterprise in Ocean sector. It unravels the structural complexity of the subject. Though the activity dynamics may always be in a changing state, it does show a pattern, particularly in respect to the major players in the field. Study of this kind at a regular time interval will throw much light on the changing pattern vis-à-vis its causal connections with the socio-economics of the region and its social requirements.

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The author expresses his deepest gratitude to Prof. Olle Persson of Inforsk, Umea University, Sweden, for his gracious help in doing this work, without which this work would not have been possible. Thanks to Prof. Robert Hanneman, University of California, Riverside who was always there to help the author to clear doubts in understanding Network Analysis.

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