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Marine science and blue growth: Assessing the marine academic production of 123 cities and territories worldwide

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ABSTRACT

The role of academic research in the economic growth process has been widely considered over the last two decades in the theoretical and empirical literature, particularly around the concept of knowledge-based economy. Meanwhile, the very recent notion of "blue growth" and the significant development potential related to marine environments have gained more and more concern for policy makers on different scales. It is therefore interesting to assess the academic research related to marine issues, owing to its potential contribution to this dynamics growth through knowledge transfers and academic spillovers. This paper provides a global evaluation of the marine academic production, using a spatialized, open and transdisciplinary approach. In particular, this approach is to mobilize indicators to assess scientific production, transpose it to the territorial scale and make a global comparison of "research territories" in the case of marine science, with a specific focus on European cities. The results show that the five main centres are Tokyo (Japan), Paris (France), San Diego (USA), Moscow (Russia) and Woods Hole (USA). A dense European territorial coverage in marine science centres also appears, and new world major centres such as Chinese and Brazilian ones emerge.

1. Introduction

The crucial importance of information, knowledge and technology in the economic growth process has been more strongly highlighted by many researchers since the 1990's. Work relating to the knowledge-based economy [1–6] showed the need to study and understand who generates knowledge, how it can spread and how the knowledge networks work. In this context where knowledge becomes "the most fundamental resource in the modern economy" [4], academic research, i.e. scientific research, appears as a strategic activity and resource. Indeed, academic research is one of the main knowledge-generating actors. It is therefore natural to wonder about the role that this actor can play in the growth dynamic, a role increasingly expected by policy makers, at a macroeconomic level but also at regional and local levels.

A first type of research activity effect on the economy is its multiplier effect: it can be called "effects on demand" or "expenditure impacts" [7]. It impacts regional income and employment. This is the direct contribution of the research infrastructure (e.g. a university) to the regional or national economy: the number of direct jobs (researchers and staffs), the local consumer spending of these researchers and staffs, or also research infrastructures spending in supplies, equipment and services. Many case studies have been conducted, especially in North America and the United Kingdom, using surveys or input-output tables [8–11]. But these "effects on demand", although interesting, are not the most important impacts. Indeed, in terms of wealth creation and economic development potential, it is more interesting to focus on a second type of research activity effect: the knowledge transfer effects, in the broadest sense. This second type can be called "effects on supply" or "knowledge impacts" [12] or "knowledge spillovers" [13]. These are all transfers existing between academics and economic supply actors, primarily industries, companies. Generally, these transfers are made through two "productions" specifically related to academic research: producing highly qualified graduates that can then be hired by companies [13,14]; and knowledge production, which can then be disseminated to companies through various channels: patents, licenses, spin-off companies, cooperation, co-funded theses, collaborative projects, publications [15–17]. The knowledge-based economy theorists focus more on this second type of research impacts – the effects on supply. The model of the Triple Helix relationships between university, industry and government [18–20] provides an interesting analytical framework.

Among the observations made in these studies, two elements call for our attention: the "size factor" and the "concentration factor". There seems to be a direct relation between the size of the research infrastructure, the amount of produced knowledge and the concentration of researchers in the same place on the one hand; and the effectiveness

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and strength of knowledge transfer observed, on the other. In other words, the more numerous researchers and knowledge – and the more spatially concentrated they are – the higher the probability of observing a large number of knowledge transfers.

In addition to these developments around the link between research and economy, the economic and demographic context in the world is undergoing profound changes. The world population growth, the concentration of inhabitants on coastal fringes, the ever-growing needs for resources, and concerns related to the environment are as many factors leading to re-assessing development models and usual economic schemes. Economic issues related to sea and ocean then become increasingly important: the terms "blue economy" and "blue growth" appear and are taken up by many institutions [21].

This paper's study starts from this two-fold observation – the link between research and economy, and the emergence of the concept of blue growth – and proposes a global analysis of the current situation and temporal evolution of academic production related to marine issues. Our approach is spatialized, open and transdisciplinary. This approach is to mobilize indicators to assess scientific production, transpose it to the territorial scale (city) and make a global comparison between "research territories" in the case of marine science. European cities are more numerous in the analysis: the European level is indeed particularly interesting because of the highly-structured EU marine policy. The paper is constituted as follows: first, an overview of the place given to the marine-related issues in recent European history is presented. Then, the paper focuses on the factors that determine the effectiveness and strength of academic knowledge transfer, and in particular the "size" and "concentration" factors. Thirdly, the method used to evaluate the academic potential of European territories in marine science is explained as based on spatialized scientometrics. Finally, the results of our comparative study are presented and analysed.

2. Policy-makers and marine-related issues: some benchmarks

First: how policy-makers – particularly at state and European Community levels – have progressively integrated marine and maritime issues, should be analysed briefly.

At the European Community level, Horizon 2020, the last and most important EU Research and Innovation program includes a part devoted to blue growth. The European Commission has defined a "Blue Growth Strategy": "a long term strategy to support sustainable growth in the marine and maritime sectors as a whole" [21]. The authorship of the term "blue growth", or "blue economy" seems to be attributable to Gunter Pauli [22]. Originally, it is more of an alternative economic model, based on the principles of sustainable development and circular economy: this model is to meet the basic needs using what is available locally. This term today refers to all economic activities related to the sea and the wealth they create, including those on the sustainable exploitation of new resources. But European policies have not always incorporated the concerns related to the sea, on the contrary. First came the Common Fisheries Policy in 1983. Then, in 1992, within the Natura 2000 network, a set of protected marine areas was created, aiming at preserving nature and socioeconomic concerns. But not until the beginning of the 21st century did the concept of EU Integrated Maritime Policy (IMP) appear in the European institutions. It was finally adopted by the European Union in 2007. This maritime policy is focused on "blue growth". The goal is to provide for a sustainable and controlled exploitation of the ocean through a comprehensive approach of maritime environment.

During the last decade, the concern of the European institutions for marine issues increased. The sea has even become a "crucial" element: "The ocean and seas are crucial for Europe. In fact our continent is the second-smallest continent in terms of its land area, but we sit between two oceans and five seas and have a coastline of 70,000 km" [21]. Several studies have attempted to estimate the growth potential linked to the sea. In 2014, Gavigan suggests estimates of 5.4 million jobs in the global blue economy, with a possible increase to 7 million in 2020. As for Mees, the Chair of the European Marine Board, he suggests at the same time a figure for the estimated gross value added of the European maritime economy: €500 billion per year. For United Kingdom only, the UK Marine Industries Alliance [23] estimates that marine-related sectors employ nearly 90,000 people, in 5000 companies, but highlights that "greater cooperation across the marine industries and maritime services sector could see their value to the UK economy rise from the current £17 billion a year to £25 billion a year by 2020". The most promising development areas are ocean energy, aquaculture, biotech and deep sea resources.

In this context, marine research gradually appears as an essential element. Since 2006, the European Commission has identified marine research as a key element of maritime policy in the future [21]. The "European Strategy for Marine and Maritime research" was adopted in 2008, and has become an essential pillar of the EU Integrated Maritime Policy. In 2010, the Commission underlined the "vital" and the "crucial" role that marine science and technology must now play in this blue growth dynamic. In its 2014 conference, Eurocean, the European Centre for Information on Marine Science and Technology, noted that the "collaborative and cross-disciplinary European research is the key to providing the knowledge and tools that we need" to ensure blue growth sustainably and efficiently. On this occasion, four main objectives were defined, three of which relate to marine research: "valuing the ocean", "reinforcing Europe's position as a global leader in marine science and technology", "building a much greater knowledge basis through ocean observation and fundamental and applied research", "breaking scientific barriers combining expertise and drawing from a full range of scientific disciplines".

Beyond discourses and objectives, significant funds have been used for years for European maritime policy. Already in the FP7 program, €195 million and 31 projects were allocated to marine and maritime research. Today, within the Horizon 2020 program (€80 billion of funding available over 7 years, 2014–2020), the first "Blue Growth Call" has resulted in a €145 million injection of funds (for 2014–2015), and the second call for projects is underway.

However, the community action sometimes masks large disparities. Faced with the need to consolidate and integrate the numerous and dispersed elements of marine legislation and planning [24], the United Kingdom has gone the furthest, by developing a comprehensive marine planning document: the UK's Marine Policy Statement [25], defined as "the framework for preparing Marine Plans and taking decisions affecting the marine environment", and whose aim is to ensure optimal exploitation of the ocean both economically and environmentally. Besides the UK's Marine Science Strategy and associated Marine Science Coordination Committee has furthered much more consistent and shared thinking than would have otherwise been the case, and has directly influenced how other countries are looking to structure future work on marine science and blue growth [26,27]. The other European countries seem to be more like "followers". Thus, among European keys-players – countries where marine research production is among the highest – France or Germany still do not have a clear overview of the budgetary effort devoted to sea-related sectors. France recently set up a National Sea and Coastal Council, to strengthen the coordination of public actions in the coastal territories and to provide the implementation of the National Sea and Coastal Strategy (SNML), but its policies remain sectoral. Another such case: Portugal, the European country with the fastest growing marine research production, initiated a Marine Spatial Plan in 2008, having first developed a National Sea Strategy in 2006: once again, if the approach appears to be necessary, its implementation still faces problems, both operational and conceptual [28].

Meanwhile, several non-EU other countries have become aware of the essential contribution that sea-related activities could bring to national economies. Thus, several national maritime policies have been created to ensure sustainable exploitation of the seas and ocean, and to frame the valorisation of activities related to the sea. For example, in 2010, one of the world's foremost producers of marine knowledge – the USA – set up a National Ocean Policy and a National Ocean Council to implement a coastal and marine spatial planning (CMSP), at the same time when several European countries did so. Among non-EU countries where marine research production is growing the fastest, China and Brazil have established marine policies since the 1990's: China with its Ocean Agenda 21 (1996), and Brazil with its National Maritime Policy (1994). Australia, Canada, Japan and Norway have also developed such cross-sectorial national strategies.

The cases are therefore different, but marine policies have clearly benefited from a stronger dynamics in their structuring and integration since the 2010's, in Europe as well as in the rest of the world.

3. Academic knowledge transfers: identifying determinants

In existing literature on knowledge transfers, whether empirical or theoretical, several factors appear to explain the success or failure of academic transfers. The paper proposes to identify the main key factors to draw a typology, without prioritizing. Particular attention is paid to the "size" and "concentration" factors to check the influence and importance of these two dimensions: the absolute "amount" of knowledge produced and the spatial concentration of this production.

3.1. Scientific factors

Several empirical studies indicate that the strength of the science-industry collaborations depends in part on the scientific discipline: some research areas have a more regular cooperation with the industry, regardless of the scientific quality of researchers. The degree of applicability of sciences, the basic characteristics of the knowledge (*tacitness*, *systemicness*, *expected breakthroughs*) and the disciplinary origins are thus the first factors [29]. In a comparative work across the OECD countries, Martin [10] observed a concentration of spin-offs on a few sectors, in particular life sciences, with biotechnology, agri-food, pharmaceutic, ICT and software. This was corroborated by the work of Martinelli et al. [30] in the case of the UK, Goldstein et al. [31] in the US and European cases, and Grossetti [32] in France, who observed that there are more contracts between laboratories and companies, and more co-funded theses and spin-offs in engineering sciences and life sciences. The quality of the knowledge produced, as well as the nature and the personality of its "producers" are also to be considered: there seems to be a function between the transfer probability and 1) the quality of research [33], and 2) the individual and organisational characteristics of scientists (seniority, publication record, patent record, vision of private activities) [29,34]. A European study on innovation and transfer policies with the Triple Helix model [16] revealed that the success of technology transfers depends as much on the substantive scientific knowledge as on the economic and technical knowledge (in terms of market potential, partnership terms, mobilized devices). But this second factor seems rather questionable, and comparative work is lacking.

3.2. Physical proximity and networks

Spatial concentration – geographic proximity between research and companies – is probably the most studied factor. Porter [35], developing his theory on clusters, emphasizes that the benefits dwindle as the geographical distance between actors increases. This findings are supported by empirical studies [36,37]. Candell and Jaffe [15] mention a local "inducement effect", some local stimulation due to academic research and the human capital that it creates: private R & D stimulation, attractiveness for companies. As for spin-offs, geographical proximity with the original research team is often observed and remains very strong. According to Grossetti [32], the implementation of these spin-offs "depends more on the social logic of creation and development resources than market-related constraints". Mansfield [33] shows that US companies are more often collaborating with geographically close universities, concluding that the probability for a company to finance academic research is inversely proportional to the distance separating from university. Coccia [38] reaches the same conclusion in the case of Italy. But this observation is not always true [39]. However, physical proximity, if it can facilitate exchanges, is not essential to the transmission of knowledge. Other forms of exchanges do exist: Torre quotes "communities of practice based on the only organized proximity" and "temporary geographical proximity (meetings, shows, conferences…)" [40]. These have the advantage of allowing cooperation between actors while partially overcoming the limits of the co-location: including conflict, imitation, industrial espionage [41]. For some projects, Asheim and Coenen [37] note the need to "combine both local and non-local skills and competences in order to go beyond the limits of the region". Boschma [42] questions and relativises the importance of geographical proximity, and distinguishes four other types: cognitive, organisational, social and institutional proximity. He notes, though, that "geographical proximity may reinforce or strengthen the other dimensions of proximity over time". Cooke and Leydesdorff [1] also stress the importance of networks created by all the researchers in the dynamics of innovation, which Coppin [43] calls the "relational capital". These networks are aware of various relations and exchanges: intra or extra-territorial, physical or non-physical, common work, market or non-market, regular or occasional. And it allows combining complementary parts of knowledge, and reinforce the actor's openness [42].

3.3. Size factor

The size of the research infrastructure is also to be considered. Martin [10], studying the local impact of Canadian universities, acknowledges the existence of a size effect: the more important the university research activity is, the greater the level of its valorisation and its integration into a local business sector, particularly in the industrial field. The notion of size effect also appears as crucial in a study on the science-industry agreements in France [44]: the authors conclude that the size and distance effects "significantly structure the spatial distribution of science-industry collaborations". Their research hypotheses are confirmed, "the collaboration between two regions are even more important as these are dense in scientific and economic resources; conversely, the more the regions are physically distant, the fewer contracts between the two regions". Likewise, Shearmur, having studied six maritime clusters, concludes that the cluster's success depends on the local potential in knowledge infrastructure, as well as on human capital, collaborations, and the critical mass of companies and institutions [45]. He also observes that clusters located in the peripheries appeared to be less innovative than those in metropolitan areas, particularly due to the low higher education supply (less research centres, major universities). This size factor is important[1]: a major university city, a metropolis or a national capital will naturally have a strong potential for academic contributors, but is also more likely to have the best researchers in the country or region, and more resources (both financial and technical) within its territory.

3.4. Contextual factors

Finally, the territorial trajectory [35] has to be considered, and the local environment or local context as a whole. The strength of the academic transfers particularly depends on the ability of local R & D

[1] For our bibliometric analysis (hereafter), it would have been interesting to collect data on the surrounding environment of the marine research organisations, especially on the knowledge infrastructure in each city. But such work is a separate study, which would require considerable effort for the 123 cities analysed.

Table 1
Key factors in academic knowledge transfers.

Key factors	Academic knowledge transfers depend on…	Indicative references
Degree of appliedness of sciences	Scientific disciplines, scientific areas	Goldstein et al. [31] Grossetti [32] Martinelli et al. [30]
Scientists' personality, characteristics of knowledge	Quality of scientific output; individual and organisational characteristics of scientists	Bekkers et al. [28] Bergman [34] Mansfield [33]
Physical proximity, spatial concentration, clusters	Local specializations, existing clusters and size, density and composition of economic sectors and labour market	Asheim and Coenen [37] Coccia [38] Fischer and Varga [39] Porter [35]
Organized proximity, networks	Density and efficiency of collaboration and knowledge networks at different scales	Boschma [42] Cooke and Leydesdorff [1] Coppin [43] Torre et al. [40,41,49]
Size of research infrastructure	Number of researchers, mass of knowledge produced	Bouba-Olga et al. [44] Martin [48] Shearmur et al. [45]
Surrounding environment, local context	Historical, geographical, social, economic and cultural context	Eriksson and Forslund [47] Fogarty and Sinha [46] Trippl and Maier [12]
Innovation policies, role of institutions	Regionally, nationally and supranationally implemented policies	Bramwell [50] Roper and Hewitt-Dundas [48] Torre [49]

networks to integrate "created" knowledge and to translate it into added value [46]. This ability not only implies a locally-based critical mass of companies, activities and skills to exploit this knowledge; but also a sufficient match between these locally existing activities and scientific areas. Eriksson and Forslund [47] have shown, for example, that in the case of Sweden, the influence of universities on employment is greater in regions with high concentration of skills able to apply the knowledge created by universities. They conclude that if the regional composition of the production system in terms of skills and activity sectors does not – or not much – match the knowledge produced, there is little chance that induced impacts will be significant. According to Trippl and Maier [12], the contextual factors are also essential to attract highly-skilled labour and talents, and thus transfer knowledge from one place to another by means of these talents' mobility. They insist on the degree of demographic diversity, i.e. the easiness of integration. Viale and Ghiglione [16], citing the case of Portugal and Ireland, also stress that the role of public research in local economic development is more crucial in the case of peripheral regions that suffer from a lack of R & D investment and from the absence of effective local policy to support innovation. This highlights the strategic role of institutions, particularly in the definition of innovation policies at different levels [48]. Torre [49] estimates that the innovation process and its link to the territory are highly dependent on the local policies implemented and resources allocated: according to him, "the role of institutions in building the geographical framework of economic interactions" is essential. Conversely, disparity and a lack of complementarity between governmental, national and regional policies for innovation and transfer hamper the effectiveness of transfers [16]. Regarding empirical studies, an interesting example would be the case of the cluster of Waterloo, Canada, in the field of ICT [50]. The success of the cluster can be explained by the strong-willed policy of local institutions and policy makers. These various studies show that the success of transfers and their "reproducibility" in other contexts and territories remain largely dependent on the history and context of these other territories, and the policies implemented, and not only on the mass or the level of academic knowledge produced.

A synthesis of these different determinants is presented in Table 1.

By applying the principles to the marine field, a relationship can be assumed between: first, the mass of knowledge produced in marine science and the concentration of this knowledge in centres (cities) and geographic areas; and secondly the probability that this academic research in marine science will result in a significant mass of knowledge transfer. This potential – this "knowledge capital" – must be therefore evaluated, as completely as possible. That is why the paper focuses on two elements:

- The spatial distribution and density of marine research centres in the world, and especially in Europe, and the characteristics of these centres (function, proximity to the sea, collaborative networks).
- The mass of knowledge produced in relation to reference centres in marine science in the world: the quantity and quality of knowledge, and the ranking of the various European centres among world reference centres.

The most relevant scale for this evaluation is the "macro" level of scientific research analysis, i.e. at the state, city or province level. So the paper focuses on territorial research systems, centered on the city to allow international comparison.[2] This evaluation is also particularly crucial in the context of "metropolization" worldwide, where local academic research could contribute to a possible specialization of the territory (within the meaning of D. Ricardo, but of a kind still to define). Indeed, knowledge is a resource that is mainly related to the human factor, human capital: graduates, highly skilled personnel, public and private researchers. But human capital is, in part, mobile and fluid, and it seeks to concentrate to benefit from positive spillovers [51]. Territorial competition is therefore no longer based on natural endowments, but more on the ability of territories to attract and retain human capital. The link between the economy, the territory and spatiality is gradually modified. "The advantage" in terms of competitiveness is then actively built, and not passively suffered. And it depends largely on the

[2] The city is also chosen as a level of analysis 1) to spatialize the marine communities as precisely as possible, and 2) to link the marine knowledge production with contextual elements (for example, geographical situation: e.g. proximity to sea).

commitment and involvement of local stakeholders, as their decisions, exchanges and policies implemented that will – or will not – allow to build and strengthen this advantage.

4. The method: spatialized scientometrics

The method chosen is first explained, then the integration of the spatial dimension, and thirdly some limitations and precautions are discussed.

4.1. Assessing the marine scientific production for 123 territories

Academic research in marine science is conducted by public "generalist" institutions such as universities, or "experts" (e.g. Ifremer in France, the Woods Hole Oceanographic Institution and the Scripps Institution of Oceanography in the USA). It covers fields such as oceanography or more technological areas: naval, maritime security, the exploitation of marine resources (energy, algae). To evaluate the academic research potential, a scientometric approach is particularly appropriate. It has especially been developed for 30 years, along with academic rankings [52]. Scientometrics can be defined as "the science of analysis and measurement of science, scientific production and network quantitative analysis" [53]. "Scientometrics generally means the application of statistical methods for quantitative (economic, human, bibliographic) characteristics of the state of science" [54]. It is based on various types of indicators that can be grouped into two main categories: indicators of means, inputs (which are based on accounting and human resources data: number of researchers, research institutions budgets), and bibliometric indicators (on scientific output). The OECD mentions several scientometric indicators among its "indicators for the knowledge-based economy", especially indicators of means [55].

The most relevant indicators have here been determined, considering the specific constraints:

- The wide diversity of actors and disciplines belonging to the marine science field (marine science does not correspond to a clearly identified scientific category): it requires exceeding the compartmentalisation of science and respecting an interdisciplinary and transdisciplinary approach.
- The lack of clarity regarding the boundary between the academic science (non-competitive research) on the one hand, and the private R & D and technical dimension (marine technologies) on the other hand.
- The level studied: the "macro" level, i.e. the territory, not just the research institution.
- The need for global comparability, identification and ranking of marine research centres on a sufficiently homogeneous database.

Indicators of means are very interesting on a limited scale. But it is usually based on national databases that do not have a sufficient degree of homogeneity for a global study. And there is no international database for these research means (broadly defined: number of researchers, research budgets, equipment). Several indicators of means had been selected at the beginning of the study, such as research workforce, research budgets and the number of oceanographic vessels, but were then dismissed because of their lack of homogeneity. Conversely, indicators related to scientific production (bibliometric) have two advantages: bibliographic databases are standardised internationally [56]; and data is available for a large number of territories, publication being the "base product" for academic researchers. The latter have been selected – i.e. those related to scientific production.

The database mobilized is the Web of Science, from Thomson Reuters, one of the main international bibliographic database, as well as the oldest. The following types of publications have been considered: papers, proceedings, reviews, letters, editorial material, book chapters. The analysis covers 123 territories. To identify the territories to be considered, a questionnaire survey administered by phone was conducted in marine research institutions.[3] This list includes – ceteris paribus – a larger relative number of European territories, so as to further analyse this scale (33 places however are not European). Two main indicators were provided for each territory: the number of publications and citation averages. On smaller panel territories, two other indicators were collected: the co-publication ratio with foreign countries and the h-index [57]; respectively for the 40 and the 30 most publishing territories. Three periods were distinguished: a long period 1975–2013), which allows a smoothing of cyclical effects and includes the dimension of research seniority; and two randomly chosen short periods (2000 and 2011), reflecting the short-term and newer dynamics.

4.2. Embedding the spatial dimension

In the same territory, not only one but many scientific contributors are to be found, potentially belonging to different guardianships. And each of these contributors is a link in a network that extends beyond the territory: his/her own network as a researcher, his/her relationships with other close or distant researchers and actors, both nationally and globally. That particular set is what deserves attention here, and what must be understood. The aim is to take into account all the researchers who produce marine knowledge in every territory. These territorial research dynamics, and the gathering of "spatialized" publication indicators, must therefore be integrated. The issue of the delimitation of the "territories" to be studied – i.e. scientific centres or places – is very important here, because results depend on that issue. Several works on the spatial aggregation of bibliometric data show the need to think in terms of urban areas for large cities [56,58,59], because the city is then a simplistic scale for these conurbations in fact comprising several cities. Washington DC (USA) or Paris (France) are good illustrations of this problem: they are polycentric scientific urban areas. Our preliminary survey to identify the territories where marine research institutions are located revealed a significant part of medium-sized cities, and a smaller part of major urban centres. As our objective is a worldwide comparison of territories, it seemed more logical not to operate groupings for these major urban centres (e.g. Paris, Washington DC, Tokyo) even if these urban entities are actually widely spread beyond the city limits. Indeed, if aggregations were made, they would also bring together small and medium cities with other geographically close cities, which would be difficult to achieve fairly. So the choice has been made to spatialize publications relying on city names and zip codes. On the other hand, there is a spatial division of the publications analysed, which is related to the number of locations co-authors come from. The "whole count" [60] has been chosen. For each publication, the cities involved thus receive a credit of 1 regardless of the number of addresses or authors associated with each of the signatory cities.

For the selection of publications to be considered, two different research equations have been used in the Web of Science. These two equations are complementary; they allow to form a corpus of "marine publications" per city:

- The first equation is a thematic one: it is related to the content of the publications (title, abstract, keywords). It comprises 113 words or terms related to the sea and the ocean, and the administrative denomination of the city (name, zip code). For every city, it captures all the publications belonging to this marine semantic field, whoever the authors

[3] 142 institutions (identified from public data: websites and directories) were contacted to collect information concerning their activity: the number of marine researchers and teachers, scientific means (vessels, test basins, supercomputers), involvement in research programs, and scientific partners. 58 institutions, in 23 countries, agreed to respond. The survey allowed a better understanding of the marine science organisation worldwide, identifying other marine scientific institutions and compiling a basic list of the territories involved. All places cited by respondents were added to the list, as well as places distinguished by the presence of one or more academic research institutions in marine science, or marine research resources. The definitive list numbers 123 territories.

may be (the only filters applied are thematic and geographical).

- The second equation is more conventional: it is related to research institutions in marine science that were previously identified by the questionnaire survey and additional research. It consists in these institutions' names and addresses. For every city, it captures all the publications of the authors belonging to these marine research institutions.

The two equations are then combined: a marine publication corpus per territory is obtained. The method allows minimizing the disadvantages of each equation taken separately.

4.3. Precautions and limitations

Although bibliometrics allow using indicators recognized by the international scientific community, several general limitations of this bibliometric approach should be noted. First, the database used – Web of Science – does not include all the scientific publications in peer-reviewed journals. The social sciences are particularly under-represented. Secondly, as for any analysis based on keywords, there is a selection bias. After having queried the Web of Science database, a relevance test was thus conducted to estimate, among the results obtained, the proportion of publications that actually belong to the marine research field, and mistakenly selected publications, which are foreign to this field. For Bergen (Norway) and Moscow (Russia), two series of 50 publications in the result corpus were randomly extracted and appraised. In Bergen, the relevance rate was 89% (89 out of 100 publications actually belonged to the marine science field). For Moscow, this rate was 81%. Thirdly, there is no common rule in writing the addresses of publications: each author signs in its own way, which is a problem, especially in the case of multi-site institutions. Additionally, our choice not to operate groupings for major urban centres can be discussed, even if it seems justified, because the corpus of captured marine publications for these large urban centres is probably underestimated. Fourthly, marine sciences are particularly multidisciplinary. There is therefore a significant mass of research on the marine topic that is not made within marine research institutions, but in other research institutions, specialized in earth sciences, geology, biology, the environment. It is necessary to take it into account. But it is sometimes difficult to identify these institutions from afar. That is why a thematic equation has been used in the Web of Science, made of thematic keywords on the sea, so as to identify all the work contributing to marine studies. Hence, all the subjects related to sea and ocean are included in our analysis, whatever their authors or disciplines. Such an equation allows avoiding any arbitrary selection of subjects and publications. Fifth, several authors have pointed out that a major weakness in much of the research based on bibliometric statistics is the lack of cross-referencing of different indicators [61]. That is why four types of indicators have been simultaneously considered: the number of publications, average citations, co-publications with foreign countries and the H-index. Finally, it should be considered that it would be wrong to regard scientometric indicators as absolute indicators of scientific output quality [53].

5. Results and analysis

This work is largely exploratory, since there is no real point of comparison on the subject. Identifying marine scientific centres, their characteristics and their ranking is thus a primary objective as well as a result. But additionally, two hypotheses are tested in particular, assuming that the importance (both quantitative and qualitative) of academic knowledge produced in marine science for a territory is highly dependent on the size of the city[4] on the one hand; and on the diversity of local scientific contributors on the other hand.

5.1. Geographic coverage: an "east-west arc" in the heart of Europe

Bibliometric analysis has allowed identifying institutions and territories that are distinguished by a truly qualitative scientific production in marine science, beyond appearances. This led us to eliminate several cities from our list because they clearly had no real international-level research activity. For Europe,[5] Fig. 1 shows the spatial distribution of the main marine scientific centres.

Two interesting elements are evidenced in this mapping.

First, a very high density of centres is noted in an east-west arc from southern Scandinavia to the United Kingdom and France, through northern Germany, the Netherlands and Belgium. These countries account for a large part of the European marine research infrastructure. This density on the east-west arc is also due to national specificities in the research organisation: for example, a dense network and a very polycentric organisation, with many medium-sized centres, characterize the UK and Germany. Conversely, marine research in France, Norway or southern European countries is more concentrated in a few major national centres, such as Brest in France and Bergen in Norway.

Secondly, most of the territories that emerge from the analysis are places that seem to have a "predisposition" to work on marine issues, in view of their location. Thus, the location near the sea (coastal cities) is a determining factor for publishing in marine science, regardless of the size of cities. Indeed, many of the cities observed are not major urban centres or national capitals, yet are characterized by a high level of marine publications.

5.2. The amount of knowledge, size of cities and diversity of contributors

Regarding the indicator of publication quantities (the total number of publications obtained using the two combined processes: thematic equation and institutional equation), widely varying situations from one country to another can be observed, but the main marine publishing centres are nonetheless clearly identified. World references that appear on the long period (see Fig. 2) show more counter-intuitive results, particularly some territories without any physical link with the sea. The five main centres are, in order of importance: Tokyo (Japan), Paris (France), San Diego (USA), Moscow (Russia) and Woods Hole (USA). Among the top 25 cities, 11 are European ones (excluding Moscow); but only 2 are in the top 10 (Paris and Barcelona).

Considering the overall ranking, beyond the cities publishing the most, our first hypothesis is not verified: the marine scientific potential of a territory does not appear to be heavily dependent on the size of the city. Indeed, the ranking according to the number of publications, whatever the period (1975–2013, 2000 or 2011) is not correlated to the size of the population in a city, and several medium-sized cities and even much smaller are well ranked. Among the top 25, eight have less than one million inhabitants. This finding can be matched to the results of Nomaler et al. [62], who observe that in some disciplines (agricultural, biological, environmental and social sciences) very small towns of less than 150,000 may still excel, while for other disciplines (several medical and interdisciplinary sciences), such outstanding performance is only observed in cities exceeding half a million inhabitants. Marine science is a specific category: including most of the above-mentioned scientific disciplines. Frenken (2014) also showed a general correlation between city size and scientific output, and stressed that a certain critical mass is needed to establish a science centre. Our results show that, in the case of marine science, this critical mass can be quite low.

Our second hypothesis is confirmed, however: the marine academic potential of a territory is highly dependent on the diversity of local scientific contributors. In fact, for each city, the results achieved in the Web of Science using the two different equations are to be considered in

[4] Cf. Section 3.3. A metropolis is more likely to centralize national research institutions, whether marine or not, and also to be a major academic centre with one or several universities: so, it is more likely to have a stronger "academic power".

[5] On a global scale, the map is more unbalanced and lacks legibility.

Fig. 1. A map of the main European cities publishing in marine science (Web of Science, 1975–2013).

details. Particular attention should be paid to the part of the results that are common to both equations, i.e. publications simultaneously captured by those two equations: the thematic equation, on the content of publications, and the institutional equation, on the addresses of identified marine research institutions. The larger that common part, the more it reflects a concentration of local marine academic research within the institutions displaying the specialization (identifiable "marine universities" or "oceanographic centres"). Conversely, the lower this part, the more it means that marine research is carried out by "invisible" contributors: those who do not define themselves as institutions specializing in marine science (sometimes only one laboratory or research team), and yet have significant marine scientific production. And these invisible contributors play an undeniable role in the production of knowledge, and are a crucial link in the networks, because locally the research actors working on similar topics will be at the basis of common academic projects or science-industry projects; or will be called together to answer demands from regional communities.

Among the 25 cities publishing the most, 14 (56%) have a below 30% part of common results in the two equations: local scientific production in marine science come from diverse contributors that are more difficult to identify a priori. Eight of these cities are capitals, often centralizing national research institutions, whether marine or not, and are also major academic centres with several universities that are recognized for the excellence of their research in biology and physics. These territories indicate the importance of the interdisciplinary nature of marine science. This is the case for the following European centres: Paris, Barcelona, Madrid, Rome, Hamburg and Stockholm.

Conversely, 11 (44%) have a part of common results in the two equations that is equal to or greater than 30%, reflecting a higher concentration of local scientific production in marine science within

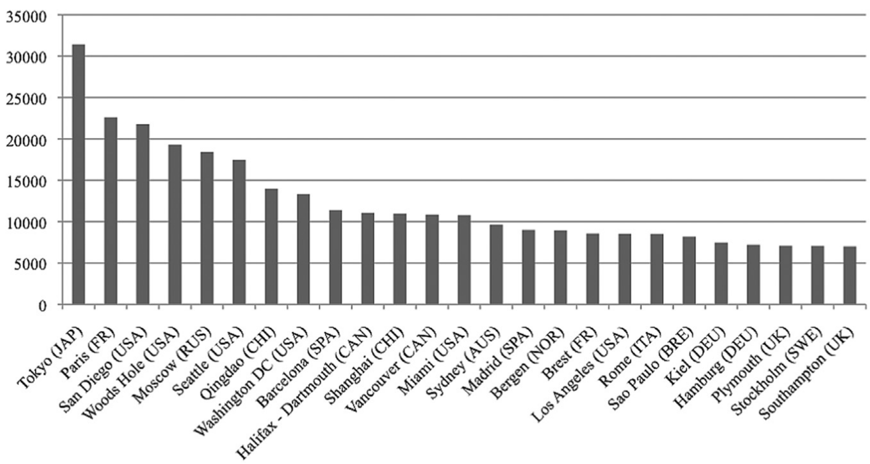

Fig. 2. Main publishing cities in marine science in the world (number of publications, Web of Science, 1975–2013).

marine and oceanographic institutions. These are medium-sized cities, or sometimes very modest, which include several types of specialized marine research institutions. Their level of scientific production is generally high as compared to their size: this is the case for the following European centres: Brest, Bergen, Kiel, Plymouth and Southampton. In most cases, those centres have made marine science a specialty, hosting a large number of various research institutions on this specific theme on their territory. They are mostly coastal cities, with a port and oceanographic vessels.

The second profile of "specialist" is assumed to be the most favorable to the creation of a real local economic system that is organized around innovation and knowledge transfer between public and private partners on the specific marine theme: to confirm this, our results should be linked with transfers indicators, such as patents.

5.3. Temporal dynamics: the emergence of China and Brazil

If the long period allows including the effect of experience and research seniority, however it masks the temporal scientific dynamics. Considering the multiplier of publications number per city between 2000 and 2011 (Table 2), a very strong growth is observed for the Chinese centres, and a significant growth for Brazilian and Portuguese centres, reflecting the emergence of these countries in the field of marine research. Conversely, most European and North America cities are characterized by moderate growth (multiplier less than 2.5).

5.4. Citations and h-index: small centres of excellence and national dynamics

The citations and h-index are more "qualitative" indicators than the number of publications, and reflect more the intrinsic quality of the productions concerned, allowing in particular to highlight outstanding though smaller-sized research teams or outstanding teams not belonging to the main publishing centres (in terms of total number of publications, the first indicator). The citations taken into account are those related to the corpus of marine publications. They were collected for the two short periods (2000 and 2011), as citations are not available for larger volumes than 10,000 citations. In 2000, the 15 centres having the highest citation averages were, in descending order: Hirtshals, Seattle, Bremen, Istanbul, Yerseke, Newcastle, Texel, Roskilde-Charlottenlund, Woods Hole, Roscoff, Hobart, Kiel, Wageningen-Heteren, San Diego, Silkeborg; therefore 10 European centres. In 2011, they were Perth, Oldenburg, Great Yarmouth-Lowestoft, Woods Hole, Villefranche-sur-Mer, Turku, Roskilde-Charlottenlund, Seattle, Oban, Cork, Texel, Los Angeles, Ijmuiden, Wageningen-Heteren, San Diego, therefore still 10 European centres.

The h-index was collected for the 30 cities that published the most in the year 2000. For a given publications corpus, it corresponds to the number x of publications cited at least x times. This is an additional indicator of the peers' recognition; it allows smoothing the information, as the most and least cited publications were not highlighted. This indicator clearly shows the national dynamics (Table 3), i.e. the different types of national research systems: centres in a same country are characterized by figures close to the h-index.

The supremacy of North American centres can be observed, and conversely, the weakness of the centres in emerging countries: Brazil and especially China. European countries are middle-ranked. The seniority of research systems partially explains those differences, since the h-index incorporates the temporal dynamics: older publications are naturally cited more. The emergence of China and Brazil on the marine scientific thematic, which was observed as to the number of publications, is not yet visible here.

5.5. Co-publications and networks

Finally, the last indicator, i.e. the rate of co-publications with foreign partners (Table 4) was collected for the 40 cities publishing the most, and over the long period (1975–2013). It allows assessing the degree of openness of marine research through the weight of foreign co-authorship. This rate is a dimensionless figure: it is the number of co-signaturing foreign partners related to the total number of registered signatures for the city.

German, Scandinavian or British cities are the most "open". Conversely, Chinese and American cities reflect more self-centered

Table 2
Evolution of marine publications number between 2000 and 2011 (main publishing cities in marine science, Web of Science, 1975–2013).

Cities (in order of decreasing multiplier)	Coeff. multiplier 2000–2011
Guangzhou (CHI); Shanghai (CHI); Qingdao (CHI)	11,7–12,4
Sao Paulo (BRE); Lisbon (POR); Rio de Janeiro (BRE)	3,4–4,2
Sydney (AUS); Barcelona (SPA); Madrid (SPA); Los Angeles (USA); Paris (FR); Bergen (NOR); Rome (ITA); Brest (FR)	2,0–2,5
Stockholm (SWE); Hamburg (DEU); Miami (USA); Southampton (UK); Vancouver (CAN); Kiel (DEU); Seattle (USA); San Diego (USA); Halifax-Dartmouth (CAN); Tokyo (JAP)	1,5–1,9
Washington DC (USA); Edinburgh (UK); St Petersburg (RUS); Woods Hole (USA); Moscow (RUS)	1,1–1,3

Table 3
H-index (main publishing cities in marine science, Web of Science, 1975–2013).

Country (according to the best national rank)	Average H-index	H-index per city (marine publications, year 2000)
USA	71.7	Woods Hole (89) – Seattle (82) – San Diego (81) – Washington DC (64) – Miami (57) – Los Angles (57)
Japan	76	Tokyo (76)
France	56.7	Paris (75) – Montpellier (55) – Marseille (49) – Brest (48)
Canada	58.5	Vancouver (62) – Halifax-Dartmouth (55)
Deutschland	55	Kiel (59) – Hamburg (51)
Spain	52	Barcelona (57) – Madrid (47)
Norway	54	Bergen (54)
United Kingdom	48	Southampton (54) – Plymouth (49) – Aberdeen (41)
Sweden	53	Stockholm (53)
Australia	50	Sydney (52) – Hobart (48)
Italy	43	Rome (43)
Russia	42	Moscow (42)
Brazil	35	Sao Paulo (35)
China	22.7	Shanghai (25) – Qingdao (22) – Guangzhou (21)

research dynamics. The sizes of those two countries, and therefore the sizes of national scientific communities can have a strong influence on their propensity to collaborate with other countries, but this does not constitute a sufficient explanatory factor: this indicator of co-publication rates also reflects national scientific practises.

Regarding our general issue – i.e. the economic potential that academic research presents for territories – co-publication data is interesting because it reflects the links between the actors of a localized research system and the outside. Those links are a means to connect the local territory to other territories, here internationally in the case of research. This indicator indirectly shows the ability of local actors to maintain networks on a large scale and to cooperate with the outside. Our results clearly indicate a collaborative research tradition for European marine science centres, in comparison to other centres.

However, what kind of privileged partners those European centres have should be studied more precisely, in order to measure the importance of “intra-European” relations, and the effectiveness of internal research networks in Europe. A detailed survey has been carried out for two territories among the European ones that publish the most in marine science: Brest (France) and Bergen (Norway), for which the bibliometric analysis was comprehensive and completed by a field survey: interviews were conducted with French and Norwegian researchers, entrepreneurs and institutions. The main countries collaborating in the scientific field with Bergen in 2013 were chiefly European ones, in descending order: the United-Kingdom, the USA, Germany, France, Denmark, the Netherlands, Spain. As for Brest in 2013, they were: the USA, the United-Kingdom, Germany, Spain, Canada, Italy, Australia. It also appears that both centres have the same ambition to establish themselves as the European leaders in marine science. But there are strong dissimilarities between them though: each has a “marine cluster”, but the Norwegian cluster is exclusively dedicated to scientific research while the French cluster includes companies.

6. Discussion

Policy-makers – particularly at state and European Community levels – have progressively integrated marine and maritime issues. Important and increasing funding has been dedicated to marine research projects. The seas and ocean have essential and crucial economic potential for national economies, as seen briefly. These policy-makers, as well as many researchers emphasize the determining role of academic research in the economic growth process, as a leading knowledge provider. Therefore, it is interesting to evaluate the current situation and temporal evolution of academic production related to marine issues, on a global scale, and particularly on the European scale: such is the purpose of this paper. Such a study had not yet been conducted, so that, points of comparison do not exist. However, the study raises two main discussion issues: first, the scope of the results, and secondly, the method (spatialized scientometrics) and the indicators chosen.

The results help to characterize the scientific production in marine science by identifying and ranking the main places, and showing collaborations practises or temporal dynamics. Those results are then a first step in the analysis of national and regional growth process based on marine knowledge. A second step would be to analyse this growth process by knowledge transfers and academic spillovers. As for regional territories, our review of the literature on the key elements in academic knowledge transfers has evidenced that the size of research infrastructures and the spatial concentration of researchers have an influence on knowledge transfer levels. So, it has been established that the observable level of academic knowledge valorisation can be correlated to the stock and concentration of knowledge available on one or more territories (even if the other key factors mentioned in the paper can have an influence). In continuation of our work, it would then be interesting to collect indicators of technology transfer, knowledge valorisation and economic blue growth, also in the marine field and for the territories identified: for example, patents, spin-offs, science-industry agreements [34,63]. And to develop a quantitative analysis to study the relations between research output, i.e. publications, and economic valorisation of such output.

The method is based on scientometric spatial indicators, especially bibliometric ones. Such indicators are relevant to assess the academic output, whatever the field. They have the advantage of being based on standardized data and thus of allowing comparison between international territories. Beyond marine science, interrogating bibliographic databases with thematic equations guarantees a broad and open-plan inclusion for each territory. The approach is reproducible, for other transverse issues, such as environmental science, as well as for more targeted scientific objects or disciplines. But the implementation of the method can be refined, particularly as regards data spatialization: the city may be a reductive scale, and the regional scale might prove more appropriate. In addition, the analysis focused on 123 cities: it could include other cities, especially non-European ones, to be more representative. And our thematic equation mobilized in the Web of Science encompassed 113 words, covering all the marine subjects. It

Table 4
Co-publication rate with foreign partners (main publishing cities in marine science, Web of Science, 1975–2013).

Cities (in order of decreasing rate)	Co-publication rate with foreign partners
Edinburgh (UK); Bremerhaven (DEU); Stockholm (SWE); Hamburg (DEU); Kiel (DEU); Helsinki (FIN); Southampton (UK); Bremen (DEU); Bergen (NOR); Toulouse (FR)	0,50–0,55
Aberdeen (UK); Barcelona (SPA); Paris (FR); Aix - Marseille (FR); Plymouth (UK); Lisbon (POR); Madrid (SPA)	0,45–0,49
Rome (ITA); Hobart (AUS); Brest (FR); Sydney (AUS); Vancouver (CAN); Naples (ITA); Mexico (MEX)	0,41–0,44
Trondheim (NOR); Halifax-Dartmouth (CAN); Los Angeles (USA); Sao Paulo (BRE)	0,35–0,40
Woods Hole (USA); San Diego (USA); Moscow (RUS); Rio de Janeiro (BRE); Seattle (USA); Miami (USA); Washington DC (USA)	0,30–0,34
Tokyo (JAP); Guangzhou (CHI); Shanghai (CHI); Qingdao (CHI)	0,20–0,29

could be wise to elaborate reduced equations, on targeted thematics (e.g. fisheries or renewable energies), to link academic knowledge and technology transfer indicators. Finally, the last indicator, the co-publications datas, provides interesting information about research networks. But the networks analysis was extensive for two cities only. Additional investigations should be conducted, by further studying scientific collaboration between all the different centres identified.

7. Conclusions

The results regarding the marine knowledge producers in the world are not surprising: the territories that publish the most are places hosting one or more world renowned marine scientific institutions. On the European scale, high-level centres are among the best in the world, but a dense geographic network in secondary centres also appears, especially on the east-west arc in the heart of Europe. More broadly, the multidisciplinary nature and the diversity of academic contributors have emerged as key elements in the creation of major marine scientific centres. Conversely, the sizes of the territories have been less decisive: whatever the indicators, many smaller cities are highly ranked, despite the fact that many capitals and major university cities are among the 123 that have been studied. Thus, marine knowledge seems to be equally developed in national capitals, medium-sized metropolises, and very modest but rather “specialized” cities. The results also show the emergence of new world major centres in marine science, especially in China and Brazil: they appear as valuable potential scientific collaborators. Furthermore, this emergence reveals that the so-called BRICS countries are very likely to play an essential role in the “blue” dynamics in the forthcoming years, both scientifically and economically.

In order to extend this research, a European INTERREG project is upcoming. It will bring together several European cities and regions to set up an observatory of the marine and maritime economy. It will make it possible to collect indicators of technology transfer (in conjunction with the bibliometrics ones used in this paper) and thus to study the relations between research output and its economic valorisation.

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