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ORIGINAL ARTICLE

Interactions between oceans and societies in 2030: challenges and issues for research

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Abstract The perception of ocean areas by policy-makers or by people, living or not on the coast, has significantly varied over centuries. Due to its vastness and complexity, the sea has been studied within distinct academic disciplines. However, the current issues related to the sea, such as climate change, marine pollution or coastal tourism, require an integrated vision of the assets and drawbacks in order to meet the challenges arising from human activities both at sea and onshore. In this study, a group of foresight officers from the French network of public research institutes decided to cross-check and compare several science approaches (biology, sociology, economics, etc) about oceans. Thus, 11 sectors of maritime activity (transportation, fisheries, energy, etc.) were cross-tabulated with 9 basic social functions (providing food, housing, learning, etc.). In this matrix, the main challenges and issues projected for 2030 were sought, in the frame of a baseline scenario. Results were clustered through 4 criteria, leading to 9 major challenges, each of them broken down into two important issues for research. The outcomes were used to create a survey, allowing the ranking of the research priorities. Most of the 9 challenges tally with the research and development objectives of great maritime states, except for governance and monitoring, which remain underscored. As a result, maritime powers still show more interest on securing national resources rather than on promoting international cooperation for secure trade and sustainable exploitation of marine resources. But foresight in this field could help changing the mentalities notably because oceans show clearly now to be a vital common good for mankind.

Keywords Ocean · Society · Marine resources · Maritime economy · Law of the sea · Foresight

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Introduction: study context, objective and methodology

Study context

Oceans[1] are becoming vulnerable because more and more issues are coming into play. For example, security and military issues are of major interest [1–3], as well as energy, considering that 33 % of oil and gas come from marine deposits, an increasing proportion over the past 40 years [4, 5]. Oceans present also promising potential for marine renewable energy with several technologies already at sea [6]. Commercial issues are also fundamental as 80 % of commodities are transported by sea [7]. Numerous activities with high economic or heritage value are linked to the sea and to its water quality: ecosystem services [8], tourism, including mass cruises [9], fisheries, desalination to produce fresh water [10], aquaculture, since fish is the 3rd source of protein reared by humans [11]. Worldwide, increasing usage and artificiality of the shoreline [12] coupled with growing awareness of the disproportionate ecological footprint left by human activity on the oceans are being observed [13, 14]. The European Marine Board [15, 16] highlighted the substantive and complex interactions between the marine environment and its ecological status on the one hand, and human health and wellbeing on the other, drawing attention to a range of important research questions and challenges on the interface between oceans and society. The movements of the oceanic mass and its physical, chemical and biological characteristics make it very complex to monitor and understand under a significant global climate change.

Oceans are now perceived as a global challenge both by politicians and general public [17]. This global challenge takes numerous aspects, owing to a large number of perceptions of the geographical space, whether intuitive or rational. Indeed, depending on the viewpoint, the sea is perceived as:

- A threat (sea-level rise, storms, piracy, etc.);
- A dumping ground (receptacle of discharges from farming, industry, cities, etc.);
- Toxic (algal blooms, invasive species, etc.);
- Useful (shipping routes, including the Arctic, aquaculture, etc.);
- A reservoir of resources (fisheries, fossil fuels, renewable energies, biodiversity, molecules, sand and gravel, etc.);
- A shelter (a safe place for endangered species in various forms of protected areas);
- A place for recreation and relaxation (culture, tourism, spas, marine parks, etc.).

[1] The terms of "ocean" and "sea" are used in this text in the broadest sense, i.e. the entire marine aquatic environment. Likewise, "societies" is meant as all human communities in all their diversity.

There are numerous studies related to one aspect of oceans, seas and seashores, but very few of them deal with a global perspective or encompass the complexity of issues related with maritime space and activities [16]. The marine domain is usually addressed by discipline or by issue: climate change, living resources, mineral resources, biodiversity, pollution, maritime safety, technological hazards, and so on. This segmented approach is not conducive to understanding the global phenomena at play or to renewing the way decision-makers consider the ocean. This observation is relevant for several other fields (agriculture, transport, industry…), notably when technology is playing an increasing role [18]. Consequently, there is a great risk that - by keeping research on the same tracks - breakthroughs and innovative issues are missed out [19–21]. Multi- or interdisciplinary research is then necessary as it facilitates the pooling of approaches, not just in terms of scientific knowledge, but also in terms of "thought systems" [22, 23]. Images or mental representations of the sea should also be taken into account, because they influence human behaviors on the scale of hundreds of millions of people, in a variety of activities like seaside tourism or seafood consumption [24].

Objective

In 2012, the Prosper network[2] decided to gather its variety of skills and expertise in foresight and research to work together on one selected topic. The French national institute of research for the exploitation of the sea (Ifremer) proposed to support this initiative, selecting the theme of the collaborative work: a shared identification of future priorities for oceanic research. The French Ministry of Research also helped this joint and multidisciplinary approach. In effect, the overall aim was to produce a comprehensive analysis of the interactions between societies and oceans in order to be able to explore and to rank the major challenges of the oceans and the related issues for research, for the next 15 years.

The time horizon set for the study was 2030 because (i) many existing foresight studies related to various aspects of oceans have already taken this time horizon; (ii) 2030 is sufficiently distant to shift trends and to provide innovations; (iii) decision-makers feel concerned about this time horizon bound to many European and national political targets; (iv) 15 years ahead seems enough to prepare relevant research task forces.

The approach should be large, beyond specialized disciplines (physics of the oceans, chemistry, marine biology, biodiversity....), including economics, social aspects and governance. As the Prosper group is rich in several disciplines, it

[2] Created in 2005, the Prosper Network is the structure of encounter, dialogue and action for the foresight officers community of the French public research. http://www.reseau-prosper.org/the-prosper-network/what-is-the-prosper-network

was an opportunity to work together with a mix of experts of the oceans and laymen, with the support of a specific bibliography. This diversity was an asset in the assessment of several maritime activities and societal functions. As Prosper experts had a limited time for working groups, and benefitted of a experienced foresight studies office (Futuribles), it was decided to select a continuous iteration of the process, starting from a basic idea: to cross maritime activities and societal functions, and explore trends and impacts in each crossing. The advantage of such approach was to benefit from two existing sets of data, one about foresight studies in the domain of the sea (prepared by Ifremer) and one about main trends in economics and societies (proposed by Futuribles). Final results could be selected by stepwise clustering. These results could be assessed by a survey proposed to a larger audience.

Methodology

The selection and fine-tuning of the method have to be done according to the objectives of the study: a scientific and multidisciplinary analysis to bring out major challenges in the coming 15 years, regarding oceanic spaces. From these challenges could be deduced logically the main issues for research.

The Prosper group observed that a strict normative approach presented a risk: this could lock up the reflection in a conventional framework that could flange creativity. Indeed, the group was aware of the need to keep the maximum of "degrees of freedom" for the reflection for three reasons: firstly, because foresight analysis in such a broad topic as "oceans and societies" requires several contributions from numerous disciplines, notably social sciences [25]; secondly, because priority has to be given to the "plausible", before the 'probable", as the actors involved in the study were numerous [26] and thirdly, because the Prosper group has to consider several criteria of quality of data from the bibliography: relevance of trends, importance of drivers, credibility of sources [27]. Consequently, it was important to select a foresight method, which could secure a "backbone" to the multiple expected interactions generated by the multidisciplinary approach. Thus, after open discussion on the pros and cons of different methods, the approach of a baseline evolution was selected by the Prosper group, with a multifaceted projection of trends and impacts as recommended for multidisciplinary studies [28]. The originality of the study remains the starting point of analysis: the systematic crossing of economic activities at sea and global societal functions.

The selected foresight method belongs to the family of baseline scenarios, according to the classification of Bishop, Hines and Collins [29]. Actually, this method produces only one scenario based on trends and impacts analysis. The modal technique is to measure existing trends and extrapolate their effects in the future by the use of cross impact matrix. This method is also included in the global group of "intuitive-logics models" which methodological orientation is "essentially subjective and qualitative, relying on disciplined intuition" [30]. According to the usual practices in this group of methods, the process is "managed by an experienced foresight practitioner" (in this study: Futuribles) and the process "asks remarkable people as catalyst of new ideas" (in this study: Prosper core group). The usual tools are, among others, brainstorming, clustering, matrices and stakeholders analysis. The method is also close to a Delphi-type study as it takes into account the three key functions of a Delphi process: brainstorming, narrowing down and ranking [31].

The time horizon of 2030 allows to avoid the risk mentioned in the dilemma of Collingridge [32]: in foresight analysis, if the horizon is too far, it is not operational; but when it is too short, it is useless. Yet, if the interactions between oceans and societies can be managed still, inaction or "business as usual" may have serious consequences on the mid-term. A time span of 15 years seems to be reasonable for efficient decisions. A second reason is that about 8 to 10 years are needed to educate and form a PhD in marine science. Another decade is required to collect and train an efficient team of research in any field and notably in marine science as data collection mobilizes several complex tools (ships, underwater robots, culture tanks…) and dynamic international networks for scientific cooperation. Consequently, it is useful to identify the key issues for oceanic research in order to be able to address them in 15–20 years. Additionally, the 2030 horizon is relevant because it allows research institutions to integrate related recommendations into their own strategy. Finally, this mid-term horizon also helps to anticipate future funding programs (e.g. after H2020, current funds for European research) providing concrete elements to the experts in charge of defining the next priority topics.

Organization of the study

Specific glossary for the study

Category: class of interactions (from a total of 370); 4 categories: (a) Knowledge and understanding, (b) Detection and measure, (c) Norms and governance, (d) Technology

Challenge: an important question involving man and his environment; to be addressed before 2030

Interaction: reciprocal action or influence of one maritime activity and one societal function

Maritime activity: all human activities at sea: inshore, offshore, and the open sea

Societal function: basic (to feed…) or possible (to learn…) activity of a human being, and/or a group

Theme for the future: an coherent assemblage of interactions inside a given category

The five phases of the study

This study took place in five phases over an 18-month period between November 2012 and May 2014 (see Table 1). The first

Table 1 Objectives, acting group and outputs obtained at each step (+ Futuribles)

Objective	Group involved	Outputs
1st phase: Defining methodology and conceptual framework	Group of 11 Prosper experts	A clear methodology for study. A grid of analysis of interactions between 9 societal functions and 11 maritime activities
2nd phase: taking inventory of interactions between 9 societal functions and11 maritime activities	Group of 11 Prosper experts	Identifying interactions between oceans (maritime activities) and societies (societal functions)
3rd phase: analyzing interactions of oceans and societies and clustering them (2 successive phases)	Group of 11 Prosper experts	(1) 370 interactions selected, grouped into initial 42 "families" and further grouped into 9 "major challenges". (2) breaking down each major challenge into 2 issues by 2030
4th phase: a survey in order to rank research issues and to gather open comments	141 people among 1200 contacts	Ranking of the 18 research issues and structuring the comments into 5 fields
5th phase: Writing study report, presentation to relevant bodies and dissemination	Group of 11 Prosper experts	Final report sent to all Prosper network members and presented to institutions of the network

initiative was coming from the core group of experts of Prosper (the authors of this paper; 4 women and 7 men, including the experts of Futuribles) using a methodology stemming from baseline scenario, proposed by Futuribles.[3] These experts are all senior researchers in charge of strategic planning and/or foresight analysis in their own research institute, close to the head of their institutes. The fields of research represented in this group are agriculture, aeronautics, biology, business and management, economics, electricity, engineering, industry process, mathematics, geography, nuclear physics, oceans, space and technology, environment and sustainable development. Several members of that group are also involved in national research programme elaboration within public thematic alliances like Allenvi (Environment), Ancre (Energy), Avisan (Health), but they were not used to produce foresight together in the same field. The challenge was to mix their different cultures and backgrounds to fully participate to a collective foresight study on a transversal topic and to answer to the Ifremer request in a short time. As a result, the criteria for experts' selection among Prosper group were their knowledge of major social and environmental issues and context of research, their own interest in the topic and finally, their availability (attendance at 10 working groups in 18 months, in addition to the preparation time). To build the specific method and secure the secretariat and follow-up, the group worked with Futuribles.

It is useful to detail the steps and the related organization of work.

The first phase of the work consisted of designing the method of work and elaborating the conceptual framework for the analysis of the interactions between oceans (11 maritime activities) and societies (9 societal functions, i.e. the role of the oceans for society) in 2030. A 9 by 11 matrix was constructed.

The group decided to use the 11 maritime activities that had been defined during the "Assises de la Mer" [33], with some precisions from a literature review [13, 34, 35]. They can be listed as follows: transportation and harbors, tourism and boating, cities and coasts, fisheries and aquaculture, mineral resources, energy, security and defense, environment and marine ecosystems, governance, knowledge and know-how, cultures and images. Articles and books related to foresight on these 11 maritime activities and published over the last ten years were collected and analyzed to find out on-going trends, uncertainties, weak signals and possible breaks. This set of data and trends was the foresight maritime bibliography specific to the study.

Nine societal functions, attempting to describe all human basic needs, were identified by the core group: providing food, security, health care, housing, production, transportation, entertainment, learning and communicating, and perpetuating.

Then, reports on global world trends and foresight studies [15, 16, 36–42] were also analyzed to identify on-going trends, and possible ruptures, impacting societies. A total of 50 societal trends were identified and split in specific tables, one table for each societal function. For example, for "providing food", seven trends were identified: demographic growth in urban areas and on the littoral, increased food consumption, attention to food safety, tensions on cultivable areas, insecure access to land, increased consumption of animal proteins, and increased demand of pure water. It leads to nine tables to fill, one by societal function, keeping in line maritime activities.

The second phase was the brainstorming time in order to fill each one of the nine societal function tables. The objective was to collect as many ideas as possible on

[3] Futuribles International is a Paris-based international, independent, private non-profit organization network on future studies. It was created in 1960 by B. de Jouvenel

the potential interactions (i.e. challenges, problems, possible ruptures or evolutions) in 2030 between each of the 50 societal trends, and each of the 11 maritime activities. This step lasted five months (Dec. 2012 to Apr. 2013). This brainstorming of the 11 experts in a participatory way entailed 370 different types of interactions; the usual brainstorming phases were successively, (1) selection by Futuribles of a number of crossings of societal trends and maritime activities, (2) written preparation of ideas of potential interactions by each expert for the selected crossings, (3) presentation of ideas in the working group, (4) discussion, selection and recording of major interactions, (5) new selection of crossings until the whole table was completed.

The third phase was analytical. The experts group's objective was to identify future major challenges as well as research issues linked to each challenge on the basis of the 370 types of interactions between oceans and societies. Two methods were used in parallel: a clustering method and an expertise method. The results of both methods were crossed and only common elements were retained and reformulated.

First method: Clustering

The Prosper 10 experts, coached by Futuribles (i.e. the "core" group), sorted out and clustered 370 interactions into 4 categories, according to the field to which they refer: (a) Knowledge and understanding, (b) Detection and measure, (c) Norms and governance, or (d) Technology. The result was 4 categories of approximately 90 interactions. At this step, the criterion for selection was the field of the interaction.

Then the experts group clustered the interactions inside each category, trying to find logical aggregations on main "themes" which could be considered as important for the future at the 2030 horizon. At this step, the criterion for selection of one interaction into a specific theme is the consistency of the interaction with the proposed theme. For example, in the global category "b", ("Detection and measure"), the core group identified 7 "themes for the future": quality of seawater, pollution, marine species traceability, fisheries and aquaculture impacts, seafood control, ship traffic monitoring, harbors' quality and security. This method of classification led to 42 clusters (or "themes for the future"): 10 were classified in the "knowledge and understanding" field, 7 in "detection and measure", 13 in the "norms and governance", and 12 in the "technology" field. Then, each cluster was considered in order to be ranked according to the number of societal trends (among 50) they could address. Whenever a cluster addressed too few societal trends, it was eliminated. This led to the elimination of 7 too specialized clusters (e.g., maritime insurance rules, game fishing…). Next, another clustering of the 35 remaining clusters was done. The core group screened the remaining 35 themes, looking at linkages among them through assembling (a), (b), (c) and (d) when they were related to the same topic. As an example, all ideas about the exploration, knowledge, modeling and understanding of marine ecosystems were assembled in a major theme called "Dynamics of marine ecosystems" or "C2" in Table 2. This process from the clustering approach led to 9 major themes (Noted from "C1" to "C9" in the Table 2).

Second method: Expertise

The core group filled out the 99 crossings, or "boxes", of the matrix (see Table 5) by using the 370 identified "interactions" and regrouping them in the relevant box. Then, after open discussion and consensus building, one key idea was selected from one box after another. The criteria of selection were the importance at the 2030 horizon and the level of urgency to address this trend, or rupture. Indeed, as these themes were dealing with several aspects of social functions all advices from the various experts were acceptable. Then, the main interaction boxes were clustered according to their logical linkages between topics and the consistency of the issues. This expertise approach led to the identification of 15 major themes (noted from "E1" to "E15" in the Table 2.).

Comparison of results of the two methods: identification of the nine major challenges

It has to be highlighted that the convergence of the results of the two methods was not easily predictable as the coaching of the method was different: Futuribles in the first case and Ifremer in the second case. Moreover, the two processes of selection of interactions (clustering vs. expertise) are radically different since the second phase. Therefore, even if the group of experts remains the same, the ways to the final selection of the major themes are different.

The 9 major themes obtained via the clustering method and the 15 major themes obtained via the expertise method were compared and great similarities appeared. Henceforth, it was possible to identify 9 major "challenges" for the future (Table 2), It does not mean that 6 themes are excluded; they are just integrated into the various relevant challenges, as shown in Table 2. In order to show the linkages between the 9 challenges and the 99 main "interactions" (from the expertise approach), the boxes of the matrix were colored according to their link with a specific challenge (Table 6). The result shows clearly the specialized challenges and the multidisciplinary challenges. It shows also the capacity of these 9 major challenges to encompass all the interactions between social functions and maritime activities. This synoptic view may be useful for decision makers.

Once the major challenges were identified, it was decided to identify two research issues related to each of

Table 2 From 15 major themes from the expertise approach and 9 major themes from clustering approach, to the 9 major challenges

15 major themes from expertise approach "E"	9 major themes from clustering approach "C"	9 final major challenges (Corresponding themes from the 2 approaches)
E1 Interface between sea and any building on shore	C1 Human health and sea	1 Understanding marine ecosystems evolutions (E10, C2, C3)
E2 Tourism, onshore and offshore	C2 Dynamics of marine ecosystems	2 Securing food and therapeutics supply from sea (E11, E12, E13, S1)
E3 Bio-remediation	C3 Impacts of any infrastructure at sea on marine ecosystems	3 Mastering the colonization of sea (E1, E6, E7, E8, E10, C3, C5)
E4 Offshore technologies for fisheries and aquaculture	C4 Risks related to the sea	4 Developing technologies for the exploitation of sea resources (E4, E5, E6, E7, C6, C8)
E5 Remote operated exploitation of minerals	C5 Management of the multiple uses of marine areas and resources	5 Preventing risks and hazards (E9, C4)
E6 Impact assessment of deep sea exploitation	C6 Development of marine technologies	6 Developing biotechnologies for industrial, sanitary or remedial uses (E3, C1, C6, C8)
E7 Synergies between marine renewable energies and living resources exploitation	C7 Security in high sea	7 Developing education, sustainable tourism and responsible social practices (E2, E14)
E8 Integrated global coastal zone management	C8 Processing and transformation of all marine resources and their impacts including bioremediation	8 Building an adapted international law of the sea (E9, E12, E13, E15, C7, C9)
E9 Safety at sea	C9 Governance; rules and regulations	9 Systematizing and globalizing monitoring and control of activities at sea (E8, C3, C5, C7, C9)
E10 Ecosystemic services: knowledge and uses		
E11 Contribution of seafood to world scale food security		
E12 International rules for sea resources management and trade		
E13 Property rules of living resources, notably on straddling stocks		
E14 Value adding for culture and game		
E15 Property rules and share of benefits for high sea resources		

them, which would allow facing changes and risks in 2030. Actually, this use of foresight as a support to research agenda building is seldom but legitimate [43, 44].

The choice of the two issues was made on the basis of two criteria: (1) their specific importance in terms of socio-economic and environmental impacts, and moreover, (2) how cross-cutting they were among academic fields, i.e. their potential to mobilize other disciplines, whether closely related or quite distant. It is important to underline the fact that these 18 items are resulting from the specific bibliography done for the study and frequently quoted in the relevant reports and studies. For instance, dealing with the 9th challenge "Systematizing and globalizing monitoring, surveillance, control and regulation of activity at sea", the foresight maritime bibliography showed that the recurrent issues are related to the necessity of reliable and world scale systems of monitoring for several applications (fisheries, ship routing, illegal traffic…) and to the security of the vital maritime flows as 80 % of goods and materials are transiting by the sea [13, 16, 35, 39, 45–48].

Of course, this selection of 18 priorities does not pretend to be comprehensive but it facilitates the presentation of the challenges with concrete and understandable research topics.

The fourth phase involved a broad consultation of maritime professionals, scientists, experts or non-experts in marine issues and other societal stakeholders. The aim was to collect their assessments of the 18 issues and related free comments, and also to rank them by importance. The survey's objective is to test the perceived importance of the 9 major challenges and the 18 issues for a broad sample of people. This sample includes scientists, who may or may not be marine experts, heads of institutions and companies concerned by the marine environment, as well as people from civil society who are not involved in maritime activities. A questionnaire was drawn up and tested within the working group, then sent out in English and French versions to 1200 individuals who had been identified by the working group, each member bringing approximately 100 potential respondents. For each challenge, the two main issues were listed so that the respondent would have a more concrete formulation of the questions to answer. He or she was asked to state the relative importance of this issue by choosing a response on a 4-level scale ("particularly important", "very important", "not important" and "no opinion"), taking into account that the relevance of the issue has to be

projected to the time horizon of 2030, that is to say in a medium term future. An additional open-ended question provided the possibility of mentioning another priority, which had not been listed. Finally, individuals were asked to make comments about the study on the whole.

The selection of external experts was an important step in the survey. To ensure an international perspective and a multi-stakeholder point of view, the Prosper group was mobilized to establish a first list of 788 experts, collecting address books of each member of the group. All of these external experts are recognized in various fields related to marine sciences, in France, in Europe and in the rest of the world. Then, this panel had been enlarged by the addition of 200 scientists in all scientific disciplines, out of marine sciences, to provide a real interdisciplinary approach to the prospective. Finally, thanks to the support of scientific councilors of French embassies and the Futuribles network, the Prosper group asked experts and decision makers from private companies or NGOs and associations in various fields: agriculture, fisheries and seafood processing, aquaculture, oil industry, nuclear energy, banking and insurance, shipping, architecture and urban planning, defense, information networks, engineering and environment studies. Most of them were involved at an international level. The final total reached 1200 contacts with approximately 30 % of non French, and 50 % of non scientists.

The fifth and final phase was the drafting of a report distributed to all Prosper network members and institutes, and the presentation of a summary of the study to the French Ministry of Research and Higher Education and Ifremer in June 2014.

Results: major challenges for societies and oceans and related issues

It is important to highlight that one of the reasons for the selection of two main issues for research for each challenge, is the will to give a clear understanding of all the items of the survey. Indeed, a large number of the participants are not familiar with the marine domain. It is also a way to increase awareness amongst all readers on the orientation given to the near future. This approach makes all the more sense that people are now aware of the usefulness of thinking about the future, including the oceans. This perception is regularly stimulated by events such as the conferences of parties about climate change (COP 21 in Paris, in 2015) or European R&D programs such as Blue Growth or long term efforts through the Barcelona convention or the Mediterranean action plan from UNEP. The key issues for research are stemmed from an abundant grey literature from numerous bodies such as Chinese Academy of Science [3], European Union [16, 38, 39, 42], FAO [11], National Science and Technology Council [46], National Research Council [35], OECD [36], SCDB [45]. The following description of the main challenges is based on these documents with the enrichment of the experts' views through a participatory process (Table 3).

Table 3 The 9 major challenges and the related key issues for research

9 major challenges	*Key issues for research*
1. Understanding and anticipating changes in marine ecosystems	*Measurement and monitoring networks* *Modeling of ecosystems*
2. Securing the provision of food and therapeutic substances from the sea	*Best practices in aquaculture* *Synergies in the continental shelf*
3. Mastering the colonization of the oceans, from shore to open sea	*Controlling coastal densification* *Environmental integration*
4. Developing safe and sustainable technologies to exploit ocean resources (energy, minerals, molecules…)	*Sustainable exploitation in deep waters* *Energy resources at sea*
5. Preventing natural and anthropogenic risks and hazards in the marine realm and managing crisis situations	*Resilience of coastal zones* *Managing risks and crisis situations*
6. Developing biotechnologies for industrial, sanitary or remedial uses in the marine realm	*Bioreducing the footprint of human activities* *Marine bio-economics*
7. Developing education, sustainable tourism and responsible social practices in relation to the sea	*Education and responsible social practices* *Sustainable tourism*
8. Building international law on a scale commensurate with the new challenges	*National sovereignty and maritime common good* *Standards and regulations at sea*
9. Systematizing and globalizing monitoring, surveillance, control and regulation of activity at sea	*Monitoring systems at sea* *Securing vital maritime flows*

The survey: results and comments

Results

Out of the 1200 people contacted, 141 answered all or some of the questions, and 126 of them completed the entire survey (Prosper experts did not answer the survey). The respondents were mostly French. There were 22 foreign nationals (i.e. 17.5 % of responses), from 10 countries: Algeria, Denmark, Egypt, Finland, Indonesia, Japan, Tunisia, Turkey, Switzerland and Ukraine. This percentage of foreigners is too low to significantly differentiate them from French respondents.

The compared responses about the relative importance of the issues are summed up in Tables 4, 5 and 6 where they are put into three groups. The ratings of "particularly important" and "very important" were considered separately then combined to better rank the relative importance of issues. The experts group did the ranking after the synthesis of all the results.

The most important or high-priority issues (group 1)

Issues scoring high for importance and low for "not important" responses (≤3):

- P 1: measurement networks (Major Challenge 1)
- P 8: energy resources at sea (MC4)
- P 15: national sovereignty and maritime common good (MC8)
- P 16: standards and regulations at sea (MC8)
- P 3: best practices in aquaculture (MC2)

Issues, which are very important, but potentially controversial (group 2)

This group of issues is characterized:

- By a high score for importance, just under that assigned to the major issues;
- But also, paradoxically, by very high scores in both the "particularly important" and the "not important" ratings. This means that the issues in this group may be controversial, except for synergies on the continental shelf (P 4) which is indicated as being very important, but not high priority;
- Modeling of ecosystems (P 2), resilience of coastal zones (P 9), mastering coastal densification (P 5), environmental integration (P 6), managing risks and crisis situations (P 10), marine monitoring systems (P 17) can appear to be "not important" for 5 % of respondents for various reasons. In particular, we noted several remarks which

Table 4 Cross-tabulated scores of issues' importance (P for "priority issue", listed from 1 to 18; MC for "major challenge", listed from 1 to 9; P1 and P2 belong to MC1; P3 and P4 belong to MC2, etc)

Item	% of responses	
Issue for research (IR) (Major challenge number)	"particularly important"	"particularly important" and "very important"
GROUP 1		
IR 1: Measurement and monitoring networks (Major challenge 1)	47	83
IR 8: Energy resources at sea (MC4)	38	79
IR 15: National sovereignty & maritime common good (MC8)	36	78
IR 16: Standards and regulations at sea (MC8)	32	75
IR 3: Best practices in aquaculture (MC2)	36	74
GROUP 2		
IR 2: Modeling of ecosystems (MC1)	26	74
IR 9: Resilience of coastal zones (MC5)	35	71
IR 5: Controlling coastal densification (MC3)	36	66
IR 6: Environmental integration (MC3)	33	69
IR 4: Synergies on the continental shelf (MC2)	24	68
IR 10: Managing risks and crisis situations (MC5)	30	66
IR 17: Monitoring systems at sea (MC9)	28	65
GROUP 3		
IR 7: Sustainable exploitation in deep water (MC4)	25	63
IR 13: Education and responsible social practices (MC7)	26	61
IR 18: Securing vital maritime flows (MC9)	25	58
IR 11: Bio-reducing the footprint of human activities (MC6)	25	55
IR 12: Marine bio-economics (MC6)	21	55
IR 14: Sustainable tourism (MC7)	13	32

indicated that issues P 5, P 6, P 9 and P 10 on risks and management of coastal zones were closely related, indicating proximity between the major challenges 3 and 5. Thus, these issues can be considered as "controversial", regarding the scattered distribution of their scores.

Issues, which are important, but controversial (group 3)

- This group of issues received only one fourth of the "particularly important" ratings and between 4 and 9 % of "not important". The issues are those directly focused on economic activities: exploitation in deep water (P 7), securing vital maritime flows (P 18), bio-reducing the footprint of human activities (P 11), marine bio-economics (P 12) and, lagging far behind, sustainable tourism (P 14), the only issue with a score of "not important" reaching 20 %.

The most important challenge is the governance of the sea as the two related issues are rated in the top five results sheet among only five priorities. The other priorities mention the lack of knowledge (MC1) and the security in terms of food (MC2) and energy (MC4). Actually, these items are vital for any scenario of securing mankind survival, even without speaking of development or sustainability. Once these basic needs are secured, the ranking is more open.

The respondents, mostly from the public research sector, logically considered the issues' degree of importance in light of how heavily they weigh on public research. This could explain that the issues more related to economic domain appear to be less important, since they are potentially dealt with by the private research sector. Issue P 14 on sustainable tourism was rated as least important, most likely because it is not a major essential activity with respect to maritime transportation, living resources, energy, and so on.

Additional proposals of questions for research

The 185 open-ended rich comments can be categorized into four groups: (1) 106 new proposals for study subjects (54 %), 32 proposals for technical, economic or social applications or solutions (16 %), 27 comments criticizing the form (14.5 %), 29 remarks of encouragement (15.5 %).

The proposals of questions to be put to research that were conveyed through the 141 responses are a remarkable addition to the subject since they are often explicit and backed by arguments. The Prosper group had analyzed the comments in a participatory way. These comments can be sorted into five fields: governance, society, science, environment and economy. The following synopsis sums up the individual responses into a few keywords for each field.

In terms of governance (mainly major challenge 8), the numerous questions can be put into three groups. The first group involves the long-term consequences of sea changes for human societies, especially the question of "strategic retreat" as the sea level rises. This preoccupation is linked to the spread and growth of coastal cities. The second group incorporates a variety of domains: ethics, related to the rules of use at sea, exploitation, protection, potential synergies of activities at sea, pollution including waste management and plastics. The third group of questions deals with the systems of measurement and control required at every level of governance, from local to global. It encompasses concerns about rules for coastal sea management, which affect a very large number of users, and problems on the global scale, such as preventing the risk of oil spills.

As for society (mainly major challenges 5 and 7), the multifaceted preoccupations expressed cover two broad types of preoccupations and expectations, which could provide orientations for research. Firstly, considering the individual and collective perception of the sea's "health" and how it is evolving, what educational approach can be proposed, from the vacationer to the Head of State, to make them aware of the issues related to the sea? Secondly, how can we ensure that all stakeholders take part in every form of useful action in order to restore the sea and its landscapes, its resources and the services it renders?

In terms of science (mainly major challenges 1, 4 and 6), four groups of proposals for research can be seen:

(1) To identify and develop technologies to reduce constraints in accessing the sea and facilitate new forms of developing value from marine resources, especially in deep sea areas;
(2) To strengthen exploration, knowledge and intelligence about the marine world, particularly to better understand its role in the Earth ecosystem and to assess its resilience to the global change underway;
(3) To develop measurement networks around oceans on a wider scale by improving standardization of technologies and parameters as well as the interoperability of networks and databases;
(4) To develop foresight studies, particularly on the regional scale, to prepare policy-makers to better anticipate the foreseeable problems linked to global change in the marine environment. This should go hand-in-hand with improving dialogue between scientists, general public and policy-makers to reduce the risks of doubt, lack of understanding or indifference.

With respect to the environment (all major challenges), three major proposals for research come to light through the following questions:

(1) What assessment criteria, information and alert systems are needed to prevent natural and anthropogenic risks and hazards in coastal zones, in particular for radioactivity (e.g. nuclear power plants located on the coast)?

Table 5 Oceans and Societies 2030 foresight exploration grid used to identify major challenges and research issues

Societal functions Maritime activities	Providing food	Providing security	Providing health care	Providing housing	Production	Transportation	Entertainment
Transportation & ports	Increasing food flows by sea	Strengthening/ harmonizing maritime good practice and control systems	Controlling entry channels and dissemination of pathogens	Distinguishing between harbor-activity zone and harbor-habitat.	Higher performance ways of organizing ports whose control is (geo)-strategic.	New optimized vessels which are cleaner and consume less, new sea routes (Arctic)	Developing tourism aboard commercial vessels, with participation on board
Tourism & boating	Developing recreational fisheries	Controlling impacts of mass activities and excesses due to luxury activities	Developing marine-health-tourism and e-medicine at sea	Development of floating/underwater habitats	Shipbuilding for residential, coastal and recreational cruise activities	Attractiveness for sea voyages (restful, exotic, contact with nature, etc.)	Saturation of harbors, coasts and spots at sea, development of virtual tourism
Cities & coasts	Urban pressure on natural spaces or those used for aquaculture	More precarious conditions for outlying habitats, social tensions and traffic	Wastewater treatment solutions, including bio-remediation	Growing competition for access to build coastal areas, urban segregation	Service sector development on coasts, industrial zones reclaimed from the sea, offshore factories	Better integration of transportation by sea/waterways in urban and inter-urban schemes	Urban renewal of port-cities, extending recreational areas seaward, towns with floating leisure activities
Fisheries & aquaculture	Strengthening and diversifying food from the sea	Better combating illegal fisheries, harmful practices and all types of trafficking	Disseminating health-foods (therapeutic virtues, food aid, etc.)	Urban pressure on natural spaces or those used for aquaculture	Boom in aquaculture (incl. offshore), technologies for quality, sustainability and traceability	Developing floating aquaculture infrastructures that can be moved	Developing recreational fisheries at sea or from shore, tourist visits to offshore installations
Mineral resources	Utilizing mineral food additives	Confrontations between states for strategic resources	Developing mineral-based nutraceuticals	Increased use of building materials from the sea	Developing high-technology extraction activities in deep water	Balance between transporting raw bulk commodities and direct processing in floating factories	Collecting seashells, pebbles and other minerals, with amateur trade
Energy	Food and marine renewables production in combination/compe-tition	Diversifying sources and greater control of old and new risks	Impacts of larger numbers of power production installations in coastal zones	Renewable energy solutions for floating or fixed habitat self-sufficiency	Hydrocarbon rebound, large-scale development of renewable energies and storage at sea	Technological developments to improve ship power self-sufficiency	Marine renewable energy tours prompting discovery and awareness
Security & defense	Monitoring and protection of food flows across oceans	Strengthening the presence of States at sea to defend their interests	Bolstering health-alert networks and inspections of seafood products	Increasingly precarious outlying areas, social tension and traffic	Measurement systems and autonomous vectors spanning civilian/military uses; fighting against counterfeiting	Improving means for ship tracking and detecting anomalies or hazards	Involving the general public in observation, measurement and warning networks
Environment & marine ecosystems	Impacts of climate change and anthropogenic pressure on fisheries resources	Developing ways to understand and act effectively on various scales	Boom in healing bio-resource sectors and bio-remediation processes	Growing footprint of constructions, disturbance of animal life, effluents	Developing engineering for sustainable facilities	Fitting ships with measurement sensors to better monitor marine characteristics	Developing eco-parks, engaging in observation and eco-remediation activities
Governance	Enhancing resource protection and management	New rules, new technologies and greater cooperation for response and intervention at sea	Developing international health standards, anticipating risks and crisis management	Increasing institutional /citizen vigilance with respect to standards and rules for the habitat	Involving the economic sector in international regulations	More stringent standards for vessels, crew qualifications and shipping rules	Engaging the public, through NGOs, in ocean governance
Knowledge & know-how	Acquiring new knowledge related to new food habits	Battles for ownership of living resources	Developing marine pharmacopeia	Research on symbioses between habitat and oceans at all latitudes	Mapping/inventory of deep sea resources (living or mineral)	Impact studies on new shipping conditions (polar route, automated vessels, etc.)	Creating more eco-parks and game software to explore ecosystems
Cultures & images	Conflicting "domesticated" and "wild" visions of the sea as source of nourishment	Evolving from an area of freedom to one under surveillance, due to multiple threats	Marine pollution, perceived as affecting the environment more than affecting health	Living on the waterfront, still a widely shared dream	An Eldorado for resources, to exploit from surface to deep seafloors. But where are the limits?	Cruises offering serenity and change of scene, luxury which is now accessible	"Immersion" in the marine area thanks to ICTs and tourist innovations

Table 6 Nine major challenges in 2030 for society in relation to oceans. Two main research issues have been identified for each major challenge

Major challenge n° 1	Major challenge n° 2	Major challenge n° 3	Major challenge n° 4	Major challenge n° 5	Major challenge n° 6	Major challenge n° 7	Major challenge n° 8	Major challenge n° 9
Understanding and anticipating changes in marine ecosystems	Securing the provision of food and therapeutic substances from the sea	Mastering the colonization of the oceans, from shore to open sea	Developing safe and sustainable technologies to exploit ocean resources energy, minerals, biomaterials, etc.	Preventing natural and anthropogenic risks and hazards (health-related, technological or societal) in the marine realm and managing crisis situations	Developing biotechnologies for industrial, sanitary or remedial uses in the marine realm	Developing education, sustainable tourism and responsible social practices in relation to the sea	Building an international law of the sea commensurate with the new stakes agreements, standards, regulations	Systematizing and globalizing monitoring, surveillance, control and regulation of activity at sea (big data, regulations, etc.)
Important research issues: *- Measuring and monitoring changes* *- Modeling of ecosystems*	*Important research issues:* *- Optimizing aquaculture practices* *- Improving synergies on the continental shelf*	*Important research issues:* *- Controlling coastal densification* *- Environmental integration*	*Important research issues:* *- Sustainable exploitation in deep waters* *- Energy resources at sea*	*Important research issues:* *- Resilience of coastal zones* *- Managing risks and crisis situations*	*Important research issues:* *- Bio-reducing the footprint of human activities* *- Marine bio-economics*	*Important issues:* *- Education and responsible social practices* *- Sustainable tourism*	*Important issues:* *- National sovereignty and maritime common good* *- Standards and regulations at sea*	*Important issues:* *- Monitoring systems at sea* *- Securing vital maritime flows*

(2) How can a framework be defined for ecosystem-based analysis of all activities at sea that will be acceptable to all stakeholders, incorporating the economic quantification of ecosystems services?
(3) How can the impact of pollution in watersheds on the sea be better measured, particularly near the coast and in all ecosystem compartments, from plankton to people?

In terms of economics (mainly challenges 4, 8 and 9), questions for research are structured along three orientations:

(1) Developing the economic potential of the sea, above all for protein sources and molecules of interest, especially via the biomass, without compromising the equilibrium of ecosystems; this means combining profitability and sustainability in a still poorly-known space;
(2) Clarifying the respective roles that international organizations, the national public and the private sectors should play in the sustainable management of the oceans, especially in the field of shipping and risk insurance (oil spills, radioactive waste, etc.);
(3) The economic assessing of ecosystems (and their functions) in economic terms in order to facilitate arbitrating choices between various development schemes, or to evaluate compensation in the case of blatant degradation of the marine environment (species extinction, chemical pollution, etc.).

As a general assessment of the proposals, it appears that the additional research questions raised are more societal than scientific or technological in nature. Thus, although the respondents consider that acquiring knowledge remains an absolute priority, the issues of mobilizing this knowledge for policy-makers and the general public immediately follow. The respondents are aware that scientific knowledge, and particularly that about ecosystems, is essential for governance, but is not sufficient. Therefore, there is an entire process of appropriation that must be stimulated or supported so that this knowledge can irrigate the policy-making process on both the local scale and the international scale alike.

Putting the results into an international perspective view and policy advice

Does this study provide a renewed understanding of the fields of action at sea and of research priorities for both policy-makers and the specialized scientific community? This question includes naturally the objective of the study.

To try to answer this question, we compared the results of the study with the ocean-related priorities of three major political entities: the United States of America [35], the European Union [38, 39], and China [3].

The USA remain a huge maritime power, with the largest exclusive economic zone in the world. This country devotes significant resources to marine science research and rank first for scientific publications in this field. At the request of President Obama (2010), the National Science and Technology Council updated its research priorities for marine sciences [46]. They differ from those in this study for three challenges: securing provision of living resources (C2), international law (C8), monitoring, control and regulation (C9) which are clearly considered as secondary issues. The most cited priority is the support to a higher economic value of marine resources and competitiveness.

For over 15 years, the European Union has taken part in various international research programs and has conducted its own actions through various research and development programs such as FP6, FP7, or "Ocean of Tomorrow". Other instruments are used to strengthen marine research ("Oceans" joint programming initiative, Euroceans conferences, Blue Growth, etc.) in order to facilitate the construction of a European marine policy. The EU Commission has set 13 priorities for the oceans, which can be perceived amongst the 9 major challenges listed in this study, but with a lack of investment in the challenges 8 (international law) and 9 (monitoring, control and regulation). And yet, although the EU has islands in every ocean of the world, it does not do much to stem benefits from this situation, particularly with respect to geopolitics.

China has made significant progress in marine research over the past 30 years. Aware that it needs to catch up in this field, China has deployed ambitious research programs. It currently has 13,000 research scientists working in 130 institutions, but still ranks only 12th for the number of publications. Prioritized efforts focus on living resources, especially aquaculture, coastal zone ecology, notably to promote tourism there, oceanography and geosciences in order to explore mineral and energy resources in ever-deeper waters. Considering this study's priorities, less importance is given to health and biosafety (C5), and, once again, to international law (C8) and monitoring, control and regulation (C9). In its plans for the 2050 time horizon, China considers that the 21stcentury is that of the ocean and has earmarked a budgeting effort comparable to that for Space [3].

A comparative assessment, analyzing the orientations of these three entities' efforts, clearly shows the shared core priorities: understanding marine ecosystems (C1), mastering the colonization of the sea (C3), exploiting resources (C4), developing multi-purpose biotechnologies (C6) and promoting education and tourism (C7). It should be noted that one of the most important challenges identified in the Prosper study is not considered at all by those three entities: the building of a corpus of international law on the scale of the global issues. Which is also quite surprising is the general lack of interest for the globalization of systems for monitoring and regulation of maritime activity. Yet, this domain should be a prerequisite for the balance of these powers and moreover for the world stability as the sea is truly the vital artery of the world economy. This results in great vulnerability to various types of crisis situations, such as piracy in sensitive passes (Strait of Malacca, Gulf of Aden) or maritime terrorism. Any serious disruption in maritime trade would have grave consequences for many countries, whether exporters, like China, or importers, seeing how vulnerable energy supplies and just-in-time trade and industry are to any blocking of transit traffic [49]. The sea remains a major concern for power, sovereignty and resources, but the key issue of monitoring and surveillance systems at the relevant scale (the whole oceanic space) still seems to be considered as secondary.

It must be emphasized that foresight studies in the maritime field are still often based on a juxtaposition of disciplines, whereas the questions should be addressed in a cross-cutting and systemic way, precisely because the environment itself is in perpetual movement [50, 51]. Furthermore, a specialized approach does not facilitate finding synergies, as shown in projects to set up offshore wind turbines, a recurrent source of conflicts in spite of the opportunities they present for mutual benefit of stakeholders and users [52–54]. The interest of using an interdisciplinary approach involving numerous stakeholders for foresight has been demonstrated, in particular for improving the resilience of coastal towns and deltas confronted with climate change [55–57]. However discussion between stakeholders is not enough, because strengthening the forms of resilience and adaptive capacity in case of overly rapid changes require fundamental epistemological and institutional developments [58–61]. Thus emerges the necessity, in the marine field as for other large ecosystems, for a capacity to adapt to global change in its multiple impacts, such as the sea level rise [62], the increase of climate refugees [63], or the risks of irreversible imbalances in ecosystems [64]. In brief, these observations justify the usefulness and legitimacy of cross-cutting approach in the research programming at the international scale, when serious issues, such as oceans and societies, are at stake.

Conclusion

This study proposed to the heads of research organizations involved in environment a new approach to future priorities for research, far from a classic exercise of programming. Indeed, the multidisciplinary approach showed to be an asset for the relevance of the study. The wide range of stakeholders in the survey group, including scientists and laymen from all professional sectors and all disciplines, provided a broad overview on the expectations of society about oceans and the scientific priorities to be addressed. In the frame of a baseline scenario, which main advantage is to give a clear backbone to

the various experts analyses, the final convergence of the two ways to process the results of the matrix (expertise approach and clustering approach), strengthened the robustness of results.

The final 9 major challenges for society are quite comprehensive because they do encompass all types of activity at sea as shown in the coloured matrix crossing the 11 maritime activities and the 9 societal functions. These major challenges are already known, but it is noticeable to find the important weight given to governance through two main research issues: first, national sovereignty and maritime common good, and second, standard law and regulations at sea. This result is important for stakeholders because these fields are not much considered today as research priorities by the dominant maritime nations. Yet, any marine policy needs an integrated processing of several assets and drawbacks in numerous fields, including notably monitoring, control and regulation; governance on the long term and in case of crisis as well. This crucial need has to be sufficiently anticipated in order to secure legitimacy, efficiency and acceptability of an integrated world-scale governance of the oceans.

Except for "entertainment", all societal functions mobilise several maritime activities and, consequently, numerous research fields. The results of the survey entailed significant priorities in five research domains, which was the second part of the initial question: measurement networks (and a better knowledge of the oceans), energy resources, governance, standards and regulations, aquaculture. Once again, this result is all the more important and useful that decision makers and funding agencies should give priority to main issues and potential synergies. These synergies are obviously numerous when considering only these five research fields. One example is given by the crossing of energy and aquaculture, as offshore platforms for wind turbines offer several opportunities for aquaculture (cages, long lines…) and moreover for measures [65–67].

But the synthesis of the free comments revealed also the perception of a lack of global and long term management of the oceans, in terms of resources and governance. It is not only a problem concerning high seas but also an issue about responsibilities in trade security, pollution control, fisheries management… and, globally speaking, in all human activities which are impacting the oceans, from the seashore to offshore. The key problem is the fact that states are still managing the oceans similarly to ground areas and this way of governance is inadequate for an open, continuous and moving medium, and furthermore, for a target of long term sustainability.

The initial research question (Which are the key challenges and the main related research issues about oceans and societies for the next 15 years?) had been addressed through a clear foresight method, a double approach in the analytical part, and a final open survey, in order to avoid the risk of a restricted and specialized answer. The development of the "Blue growth" (i.e. the economy related to the oceans), which is frequently presented as a huge and promising field of resources and employment, notably in Europe, could benefit of some insights from foresight analysis. Indeed, the development of human activities at sea has to be all the more cautious about long term sustainability that the oceans are after all one of the last and major common goods for mankind.

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