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Food for Thought

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Contributing to ecosystem-based management: a personal scientific journey

Verena M. Trenkel*

DECOD (Ecosystem Dynamics and Sustainability), Institut-Agro - Agrocampus Ouest, IFREMER, INRAE, rue de l'île d'Yeu, BP 21105, 44311 Nantes Cedex 3, France

*Corresponding author. DECOD (Ecosystem Dynamics and Sustainability), Institut-Agro - Agrocampus Ouest, IFREMER, INRAE, rue de l'île d'Yeu, BP 21105, 44311 Nantes Cedex 3, France. E-mail: verena.trenkel@ifremer.fr

Food for Thought articles are essays in which the author provides their perspective on a research area, topic, or issue. They are intended to provide contributors with a forum through which to air their own views and experiences, with few of the constraints that govern standard research articles. This Food for Thought article is one in a series solicited from leading figures in the fisheries and aquatic sciences community. The objective is to offer lessons and insights from their careers in an accessible and pedagogical form from which the community, and particularly early career scientists, will benefit. The International Council for the Exploration of the Sea (ICES) and Oxford University Press are pleased to be able to waive the article processing charge for these Food for Thought articles.

Abstract

After three decades of working as a research scientist, I am stepping back to consider the events, questions, and principles that have guided my scientific journey. Important questions and research objectives have been how to implement the ecosystem approach to fisheries management in practice, the development of new data uses, the application of new observation methods and models, and estimating and accounting for uncertainty. Stakeholder engagement—why and how—is a topic that has increased in importance over time. While our observation methods did not change much over many decades, they are now changing rapidly due to new technological developments, but also societal and environmental changes.

Keywords: ecosystem-based management; observations; modelling; uncertainty; stakeholders

The beginning

Having grown up far from the sea in the industrial car manufacturing area around Stuttgart in southern Germany, it seemed unlikely that I would end up working in fisheries science and marine biology, but I did. While the career path was not laid out and I did not even know such a path existed while I was young, taking opportunities as they presented themselves led me from biology to statistics and the combination of both to contribute to terrestrial and marine natural resource management, as well as carrying out research in several countries.

Wanting to obtain a broad education, I enrolled for biology at the University of Stuttgart in 1986. At the first lecture in biophysics, we were given the advice that programming was a useful skill for biologists, though not part of the official curriculum. At the time, as a registered student, it was possible to attend any university course. So together with several hundreds of engineering students, I embarked on learning how to structure a computer program and to master the programming language Pascal. Looking back, learning how to program was decisive for my scientific career, while it did not even count for the biology degree! Having finished the 2 years of foundation courses (Vordiplom in German), I set off to study for 1 year abroad in western France to improve my French. In Brest, I discovered by chance the existence of a marine biology master program and was able to convince the university to let me switch courses. The decision changed my career path. Back in Germany, I continued in marine biology at the University of Kiel. At the end, after a research project during which I carried out serial dilution experiments to study grazing in the microbial loop (Detmer et al. 1993) and a simulation study to be able to draw more general conclusions, I concluded that I was better at the simulations than the experiments but needed some additional training in statistics. Therefore, after finishing my studies in Germany and a few months working at the Marine Resources Assessment Group (MRAG) in London (UK), I embarked on a master program in statistics at the University of Kent (UK). Keen to apply my new statistical knowledge, in 1993, I applied for a position in red deer population dynamics modeling at Biomathematics and Statistics Scotland in Aberdeen (UK). During the interview, I was asked whether I was also interested in another position in the same project, for which they were also interviewing. I was, and became employed as a project statistician without officially having applied for it. Luckily, I was allowed to use my project results to register as a part-time Ph.D. student at the University of St. Andrews (UK), with Steve Buckland as supervisor (and boss). The 4 years spent developing a Bayesian management model for red deer, and being involved in the project management, were very formative. Red deer management has much in common with fisheries management, not the least because of a diverse stakeholder community and the use of age-based population dynamics models (Trenkel et al. 2000). Given this similarity, I proposed to apply the developed approach to salmon during a postdoc at the French National Agricultural Research Institute (INRA). The various detours I made on my educational and scientific journey provided me with the technical and language skills needed to apply in 1998 for a position as a research scientist in quantitative fisheries science at the French Institute for the Exploitation of the Sea (IFREMER). I have been working at IFREMER ever since as a research scientist and, more recently, also as research unit manager, taking on scientific and managerial responsibilities when opportunities occurred.

Approach to science

Looking back across all these years, the tools and traits that have served me well on my scientific journey are curiosity and the willingness to take a new turn on the road, logical thinking, and a critical mind. I applied them to a number of questions and topics, coming back to them repeatedly from various angles with different methods.

The methodological approach chosen for a given study was often inspired by a talk I heard at a conference. While listening, I would tell myself that the presented approach would be suitable to address a certain problem or could be applied to a case study I had been thinking about, or simply that I was curious to find out what the approach would allow us to learn about the exploited marine ecosystems around France. I have identified interesting case studies based on discussions with colleagues and the fishing industry, in response to their questions and needs for scientific management advice. Another source of inspiration for designing research studies has been European project calls. I have taken the call descriptions as a starting point to think about which open questions I could address, which method I could try, and for which case study.

Over the years, I have generally been involved in more project proposals than what I could realistically work on, even in collaboration with Ph.D.s and postdocs. Therefore, I was always glad that not all project proposals were accepted. For me, the thinking that has gone into preparing a project proposal is not lost, even if the project is not funded. It will become the foundation for other projects. The same applies to studies that did not lead to the expected results. I realize that it is difficult to accept that not all research efforts will lead to success, but in my experience, the time is well invested. Even inconclusive studies contribute to scientific progress, e.g. because they make us realize that the initial hypotheses were wrong or the data were unsuitable for the question we wanted to study. I have published scientific papers on topics I had not planned initially because I ended up studying questions the data would allow me to answer instead of the planned ones, which it did not. From my experience, curiosity and critical evaluation of hypotheses, data, and results might lead you to take a new scientific turn.

Clearly, there are many approaches to science; all are valid. Follow your own. A topic I have been working on in different projects is ecosystem-based management. An important aim has been to contribute to the toolbox for its practical application.

Ecosystem-based management

The ecosystem approach to fisheries management (EBFM) was under discussion when I joined the field in the late 1990s. Its implementation has raised many questions and issues over the years, many of which I have tried to explore. For example, how to define the approach? Which tools and methods are fit for purpose? Do we need to know and account for everything? It seems easy to lose the plot faced with the many challenges ahead on the road to implementing EBFM (e.g. Cowan et al. 2012, Ramirez-Monsalve et al. 2016). Like other colleagues and inspired by the work of Jason Link, I have tried to contribute to concrete solutions that would permit making first steps, such as my proposal to compare total catch advice across species to overall ecosystem productivity (Trenkel 2018). Further, while the components of marine ecosystems are highly connected, I concluded that it might not always be necessary to account for all components at fine spatial and temporal scales to provide useful management advice or gain insights into ecosystem functioning and changes. For example, wider ecosystem changes might manifest themselves on the population level as changes in natural mortality or in mean weight-at-age. Thus, a first step for accounting for these changes in single species stock assessments and management is to incorporate time-varying parameters, an approach currently used for a number of ICES stocks (see review in Trenkel et al. 2023). A step further could be the use of multispecies models, tailored to account only for relevant interacting species, as already implemented in certain areas. I believe ecosystem-based management of fisheries and other human activities will benefit from the use of a diversity of context-specific approaches and models, some more operational, others providing fundamental process insights. This offers opportunities for young (and not so young) scientists to contribute fresh ideas and new methods.

The fundamental question of which model is suitable for the (ecosystem-based) management issue at hand needs to be considered every time (Dickey-Collas et al. 2014). We simply cannot become tired or too lazy to ask it! Generality, realism, and precision are three main model attributes that can guide model choice (Levins 1966, Dickey-Collas et al. 2014). Causal understanding helps to achieve generality, which stresses the importance of using knowledge on ecological processes in model development. Ecological process theory has been the foundation for my work on indicators for evaluating the impact of fishing on fish populations and communities (e.g. Rochet and Trenkel 2003, Trenkel and Rochet 2003). Actually, my colleague Marie-Joëlle Rochet and I only started to work on indicators because we wanted to contribute to the "Mini-symposium on defining the role of ICES in supporting biodiversity conservation," which was convened by Jake Rice and Mark Tasker at the ICES Annual Science Conference in 2000. At the time, we were working on discards and so we first thought about the use of fisheries catch information to estimate biodiversity indicators and then moved on to consider in a broader context indicators suitable for identifying fisheries impacts on ecosystems. We quickly realized that, for indicators to provide guidance for management, the underlying causes of the observed changes had to be identified. More generally, our research on indicators convinced me that making the distinction between causality, hence ecological processes, and spurious correlations is needed for science to provide a sound evidence base for management actions. However, to be able to do this, we need suitable data and use it appropriately. The importance of suitable data led me to start a research stream on observation methods, whose components were shaped by curiosity and opportunities, both in terms of funding and collaborations.

Observing the ocean

Establishing causality and providing relevant ecosystem-based management advice require data for marine socio-ecosystems, including for human activities. Considering that not all necessary data were available for taking an ecosystem perspective, I started to take an interest in new underwater observation methods. Luckily, IFREMER has several engineering departments working on underwater observation methods, which provided in house expertise for me to test observation methods at sea. Further, to analyze and model the data correctly, I wanted to understand the relationship between observations and the real world. It is actually in the area of observation methods that my curiosity has found its largest playground. It has led me from being interested in using videos as a possible means to obtain unbiased abundance estimates, which it does not provide (Trenkel et al. 2004), to studying bottom trawl catchability, only to realize the inherent large variability (Trenkel and Skaug 2005, Doray et al. 2010), to exploring alternative ways to use acoustic data beyond biomass estimation, which is possible (Trenkel et al. 2008, 2011). More recently, I have been studying how environmental DNA could complement scientific bottom trawling (Veron et al. 2023). For several of the studies testing observation methods, I organized dedicated surveys. Being the chief scientist was very formative (cruise proposal writing, funding acquisition, scientific and logistical cruise planning, on-board adaptation of plans to reality, etc.). I recommend the experience, in particular to young scientists, even though it might seem a daunting task, which indeed it can be.

To identify causal links between fishing and ecosystem states, we might have to go beyond quantifying fishing effort globally (e.g. as number of days at sea). Fishers use a diversity of fishing gear to target different sizes and species, and any given fishing gear will have its specific selectivity. In addition, this selectivity might vary in space and time. I followed from a distance the debate about fisheries-induced evolution caused by size-selective fishing, which I came across in the early 2000s (e.g. Olsen et al. 2004). At the time, I was wondering about the cumulative selectivity of multi-gear fisheries, as is the case in French fisheries. The question of the effects of selective fishing was taken to the community level some time later, leading to the proposal of balanced harvesting (Garcia et al. 2012). This made me wonder again about the size selectivity of different fishing gear and whether it was possible to observe cumulative selectivity effects empirically, not only in simulation models. Of course, such a field study requires comparable ecosystems that are differently fished. The first disenchantment was that comparable ecosystems do not really exist. Different gears are generally used because the habitat is different and, consequently, the species differ. To attempt nevertheless an empirical evaluation, with my colleagues we finally identified two small sites in the Bay of Biscay around 100 km apart, with one site primarily fished by passive gears and the other by active gears (demersal and pelagic trawlers). Comparing observation-based fish community metrics revealed only small differences between the two sites (Fauconnet et al. 2015). Until now, I remain undecided about to what degree cumulative fishing pressure across gears with different selectivity is size selective and what impact this has on fished communities, and hence what conclusions should be drawn for ecosystem-based management and technical fishing gear measures.

Like many people, I learned about the DNA double helix at school. During my subsequent university studies and research, I did not closely follow the progress made in genetics and related fields. In 2012, I came across a new method for obtaining abundance estimates called close-kin mark-recapture (Bravington et al. 2016). The method relies on using the number of related individuals in a sample to estimate the number of individuals in the population. Related individuals can be identified based on their genotypes. The potential of this method for carrying out stock assessments for some populations for which traditional fisheries-independent observation methods (e.g. scientific bottom trawling) do not provide much data struck me straight away. So, together with some colleagues and the help of Mark Bravington, whom I first encountered in London in 1992, I embarked on testing the approach for thornback ray (*Raja clavata*) in the Bay of Biscay, north-eastern Atlantic (Trenkel et al. 2022). The journey was challenging and much longer and windier than anticipated, involving difficulties with sampling, genetics, and interpretation of results. It also required acquiring a sufficient understanding of single-nucleotide polymorphism (SNP) for being able to analyze the resulting data, which was new for me. The reason why I developed this new expertise was that we could not find anybody with the appropriate genetic data analysis expertise who was interested in the objectives of the study and that funding was limited. Beyond providing abundance estimates, the results also revealed an unexpected small-scale population structure of thornback rays in the Bay of Biscay, which in turn raised new biological questions and also over the definition of management units. I suspect that massive genotyping will in the near future reveal small-scale population structure for many more species, in particular elasmobranchs, which do not have an egg-drifting phase and hence no larger-scale mixing of eggs and larvae occurs. Such insight will probably also launch new studies and discussions on the definition of management units, the trade-offs between biological realism and management practicality, with constraints coming from avoiding overexploitation and at the same time over-complication of management by too small management units.

Having started to look into genetic data in a wider sense, I realized that much progress has been made in recent years, offering new opportunities for acquiring useful information. The estimation of age using DNA methylation-based biomarkers is such a new possibility (Anastasiadi and Piferrer 2020). I am curious to see the results of our ongoing project applying this approach. Methylation-based age estimation might allow for non-lethal age estimation. It would further overcome age-reader variability inherent in otolith-based age estimation, which might also be achieved by machine learning applied to otoliths (e.g. Bojesen et al. 2024). The analysis of DNA traces in water is also making rapid progress. Beyond providing insights into species diversity (Rozanski et al. 2022, Veron et al. 2023), environmental DNA (eDNA) has the potential to provide abundance indices, e.g. via quantitative eDNA analysis (Yates et al. 2019) or haplotype counting (Halvorsen et al. 2023). The different methods still need to be tested for different species and confirmed under various environmental conditions to establish their limits, but the door is open to revolutionize the way we collect data in support of fisheries management and the wider ecosystem approach in the near future!

While I have taken a keen interest in applying new observation methods, optimally using existing data has been the motivation for a second data-related research stream. In this research, my focus has been on developing new statistical models to support fisheries management needs. I will illustrate this with a few examples.

Innovative data use

The gold standard for stock assessment modeling is the use of age-based abundance indices and catch-at-age data. This is stock-data category 1 in the ICES world. Production models using global abundance indices and catches are mostly ICES stock-data category 2, although some production models that disaggregate stocks into two or more life stages are considered category 1. Assessment approaches combining biomass indices (from surveys or fisheries catch-per-unit effort) and length indicators are in category 3. In the latter case, simple ratios of average biomass indices are calculated. However, alternative data uses are possible, but for this, we need to think outside the box. For example, for blue ling (*Molva dypterygia*), we developed a stock assessment model using only proportions at age and total catches (Trenkel et al. 2012). It is also possible to fit a population dynamics model to only abundance indices, as I have shown for anchovy (*Engraulis encrasicolus*) using only a recruit and an adult scientific biomass index, as well as making a few assumptions (Trenkel 2008). In both examples, the use of models with random effects offered a flexible way to handle random variations, which we cannot or do not want to model in more detail, and still keep the lid on the number of model parameters and maintain parameter identifiability. I take from these experiences that while one approach (e.g. a certain type of stock assessment model) might not fit all cases, statistical modeling offers much flexibility for tailoring the model definition and the parameter fitting method to the species and data at hand. All it takes is curiosity to learn and try new approaches—in short, to think outside the box.

Making best use of the data available is comparable to trying to cook a recipe with some ingredients missing or only potential alternatives being available. The fundamental questions for me have always been, which data (ingredients) are essential and which can be replaced or avoided with some imagination (model assumptions, random effects, prior distributions, etc.). From my somewhat experimental approach to cooking, I know, however, that certain shortcuts or modifications of recipes do not work and that not all ingredients that taste nice individually make good companions. I think the same applies to some degree to modeling.

Ever since modeling red deer population dynamics applying a Bayesian approach for parameter estimation, appropriately estimating uncertainty has been an important goal for me. To achieve this, I explored various methods for experimental design and statistical data analyses. Accounting for uncertainty has become a structuring objective of my research, as I will illustrate now.

Uncertainty

Uncertainty is all around us when working in and on the sea. Observation uncertainty is created by measurement accuracy and bias, sampling design, and natural variability. Modeling adds another layer of uncertainty due to model structure, parameter values, selected scenarios, etc. When I started my scientific career, computational power was sufficiently advanced for quantitative data analysis and advanced statistical modeling on a desktop machine. Around that time, fisheries science started to explore ways to handle uncertainty in fish stock assessments and forecasts, without being able to identify a single best method (Patterson et al. 2001). However, it was clear that uncertainty had to be quantified and it has become standard practice to do so.

Comprehensively accounting for uncertainty when drawing inferences from observational data has been important for my own work, e.g. for detecting time trends in single (Trenkel and Rochet 2003) and multiple ecological indicators (Trenkel and Rochet 2010). It has also motivated me to apply rigorous sampling protocols to be able to obtain quantitative observations, even when this meant using a car park chain to calibrate the observation width of the video camera of the ROV Victor, which we used to estimate the density of deep-water fish (Trenkel et al. 2004). Fortunately, the ROV engineers were willing to put the red and white parking chain in the transport basket, and once the ROV had descended to the sea floor lay it out in a straight line to measure the observation width at a certain height of the video monitor. The ROV pilots then had to keep the camera angle and ROV distance to the sea floor constant for the 9 days of observation transects! These days, there are easier ways to establish the observation surface of video observations.

Model uncertainty is an integral part of overall uncertainty when analyzing data or studying scenarios of potential futures for fisheries and ecosystems. In my modeling work, I have applied the principle of parsimony using simple models for the topic to be studied to maximize interpretability and generality. For example, a simplified functional group-based food web model developed by my collaborator Geoff Hosack from CSIRO provided novel insights into historic density-dependent and density-independent changes in the Bay of Biscay marine food web (Hosack and Trenkel 2019). To ensure unambiguous model parameter interpretability, I have also kept an eye on parameter redundancy, ensuring all model parameters are identifiable (Trenkel 2008). A model is considered identifiable if every parameter set gives rise to different observations. Identifiability is the condition for model parameters being interpretable.

Estimates of absolute numbers, such as the number of individuals in an exploited stock, are generally more uncertain than estimates of abundance time trends. Ecological theory allows prediction of expected directions of change, which, in a reverse process can be used to identify the potential processes behind the observed directions of time trends of population and community indicators. Let us consider a simple example. Mean size in a population decreases when recruitment strength increases, given everything else remains constant. However, mean size in a population can also decrease when the mortality of older individuals increases. This means that time series of several indicators are needed to identify process changes unambiguously (Rochet et al. 2005). However, this is still not sufficient to provide robust management advice. We also need to carry out a qualitative evaluation of population or community status at the beginning of the indictor time series to be able to classify observed changes as improving from a degraded status, etc. (Rochet et al. 2005). In summary, without needing the certainty of absolute numbers, qualitative evaluation of initial status combined with joint trend analysis of a suite of indicators can be the basis for providing fisheries management advice, as outlined in Trenkel et al. (2007). The approach has the advantage that we can benefit from what we can know with relative certainty, i.e. time trends and rough relative initial status, without needing to rely on very uncertain estimates of absolute numbers.

Qualitative modeling, aka loop analysis, offers a way to determine the sign of direct and, importantly, indirect pressures on the state of ecosystem components. Jeff Dambacher, whom I encountered during a research visit at CSIRO in Hobart (Australia), introduced me to the approach. The basis of qualitative modeling, as for all causal modeling approaches, is a diagrammatic representation of relevant system components and drivers, and their causal links. I have found the discussions around the creation of such conceptual representations insightful, and sometimes heated when participants struggle to agree on what components and links to include in the directed graph and what signs the links between components should have. Indeed, the creation of the directed graph is the moment when it becomes clear what we know and, in many cases, what we do not know. It is also a powerful tool for focusing discussions with other scientists and stakeholders. Qualitative modeling helped us to derive expected directions of change of population indicators under different pressure changes (Dambacher et al. 2009) and to carry out qualitative management strategy evaluation (Trenkel et al. 2015).

Overall, I believe strongly that we need to be honest about uncertainty in research results and management recommendations. Appraising the (un)certainty of the scientific evidence base is fundamental for managers and policymakers (Bainbridge 2014). As a reviewer and associate editor, I have been asking authors to provide uncertainty estimates, and I will continue to do so. Actually, my first editorial experience dates back to 2000, when I became an associate editor of Computational Statistics and Data Analysis, and amplified when in 2004 I joined (until 2012) the team of editors of the ICES Journal of Marine Science (Payne 2004). I was the first female editor since the creation of the journal in 1926. Other female scientists subsequently joined the team, leading to near-gender balance in 2009 (Fig. 1). I have also been an associate editor for the Canadian Journal of Fisheries and Aquatic Sciences (2013–2019), the Journal of Applied Ecology (2014–2023), and co-editor-in-chief for Aquatic Living Resources (2015-). Over the decades, being a journal editor has been both interesting and rewarding for me. Interesting, as it led me to read about a wide range of topics, and rewarding because I was able to help my peers to better present their scientific studies and apply rigorous statistics, and at the same time improve my own writing.

The general context of my research activities has evolved over the years. I have been increasingly thinking and discussing with my colleagues the ethical dimensions of our work, in particular with respect to observation methods, and the role we have as scientists in and for society. Central issues are ethics and advocacy.

Ethics and advocacy

An increasingly important issue for scientists, including myself, are ethical considerations. Ethics have been discussed for a while in the scientific fisheries literature, primarily with respect to wild-capture fisheries and whether fish feel pain (e.g. Diggles et al. 2023). Ethics also play a role for how we carry out science. I agree with Costello et al. (2016) that all negative impacts of scientific activities should be explicitly justified. The drive to reduce the ecosystem impacts of our observations needed for advising the management of fisheries and increasingly other human activities, e.g. marine renewable energy, has been an incentive for me to look into new observation methods (e.g. Trenkel et al. 2019). I believe strongly that scientists also need to apply an ecosystem approach to their own activities, including data collection and analysis, experiments, and consumables and of course travel. Indeed, the scientific community is moving in this direction and I now think twice about attending a conference or meeting in person, in particular if the only way to get there is by plane. The expected scientific gain really needs to warrant the environmental impact.

In parallel to ethics becoming increasingly important for the execution of experimental and observational research, the role of scientists in the public and at the science-policy interface has become the subject of debate in recent years. A central point of the debate is whether scientists should carry out public advocacy or not (e.g. Boon 2019). At the same time, certain scientific institutes, including my institute, have created committees, produced guidelines for the deontology of research, and defined rules for intervention in the public debate in the name of the institute. A central issue is scientific integrity. I very much welcome this debate, which is important for science in general and particularly for fisheries scientists, as our results and advice often link directly to management measures and policy development. As a scientist, I am striving to be as objective and comprehensive as possible when providing scientific results, evaluating scientific research proposals, manuscripts, or candidates, and contributing to the work of scientific committees. Scientists can provide insights into the potential consequences of different policy choices, including unconventional ones, but I believe that the actual choice needs to be made by society, which will have to live with the consequences of the decision. What counts for me in the context of fisheries management is moving in the direction of sustainable exploitation, not the exact path taken to get there.

An ethical question I have debated with my colleagues concerns funding sources. An important condition for me is that the funding body does not interfere in the interpretation of results and that all research findings can be made publicly available. If this condition is not met, I will not consider the funding source.

The interaction between scientists and stakeholders might raise ethical issues in certain circumstances, though I have not experienced this. For a scientist contributing to the sustainable management of marine resources, the interaction with stakeholders is one way to identify societal needs. Indeed, a certain number of research projects I have carried out aimed at answering practical management questions from stakeholders, mainly the fishing industry. The role stakeholders have played in my projects has changed over time, not the least driven by funding sources.

Stakeholder engagement

The contribution of fisheries and marine ecosystem research to meeting societal needs is self-evident. The way stakeholders engage and contribute to research projects has, however, evolved over the last two decades. For my research, this change came about when EU-funded projects needed to involve stakeholders to be eligible for funding. The question was then how to do this. As I observed, stakeholder engagement occurred often as an add-on to the project, when all research questions

Figure 1. ICES Journal of Marine Science editorial team in 2009. First row from left: Sarah Kraak, Audrey Geffen, Verena Trenkel, and Oxford University Press representative. Second row from left: Rochelle Seitz, John Ramster, Pierre Pepin, William Turrell, Emory Anderson, and Andy Payne.

and approaches were already defined. This only left a small space for constructive stakeholder participation.

Fishery stakeholders are diverse in type and the geographic level they operate at, from local to international (Lorance et al. 2011). On the local level, fishers are important observers of marine ecosystems and hence can be pertinent providers of knowledge on ecosystem changes (e.g. Prigent et al. 2008) or provide feedback on the suitability of management measures for specific fisheries (Lorance et al. 2011). In contrast to this more one-way relationship between scientists and stakeholders, the fishing industry has taken a front seat in a project (H2020 project Pandora) in which I have been involved more recently by leading work on fishers' self-sampling of catch compositions (Mackinson et al. 2023). Exchanges with an anthropogeographer during this project made me realize the implications of different levels of stakeholder engagement in research projects and the conditions for successful engagement (Köpsel 2023). The five levels of stakeholder engagement proposed by Stauffacher et al. (2008) are information sharing, consultation, cooperation, collaboration involving knowledge co-development, and empowerment of stakeholders. Different levels can occur at different stages or for different objectives of a project. Joint problem definition as well as some degree of co-dependency between scientists and stakeholders, the motivations and expectations of the engaging scientists, as well as sound project and budget planning were identified as key aspects contributing to our successful stakeholder collaboration in the Pandora project (Köpsel 2023).

While co-construction with stakeholders is crucial for fruitful stakeholder engagement in scientific projects, this might not be straightforward in the case of projects with broad research objectives, multiple diverse stakeholders, as well as several scientists. In this case, the lower level of stakeholder consultation might be all that can be reasonably achieved without exceeding the necessarily limited project budget. Thus, before embarking on the inclusion of stakeholders in research projects I recommend to define the anticipated stakeholder engagement levels, be honest about your motivations and make sure the necessary means (time and money) are appropriately planned. This is easier said than done, a lesson I relearn with each new project.

Final thoughts

As my scientific journey continues, the questions that have shaped over three decades of my scientific work remain and hopefully will lead to new fruitful collaborations, learning and applying new modeling approaches, and testing new observation methods made possible by rapid technological progress. The modifications of marine ecosystems by climate change and the repercussions on fish and fisheries, as well as the arrival of new human activities such as offshore wind farms represent challenging and interesting times for marine scientists!

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Data availability

No new data were generated or analyzed in support of this research.

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