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What natural and social scientists need from each other for effective marine environmental assessment: insights from collaborative research on the Tomakomai CCS demonstration project.

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What natural and social scientists need from each other for effective marine environmental assessment: insights from collaborative research on the Tomakomai CCS Demonstration Project

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ABSTRACT

We propose actions to guide collaboration between 'natural' and 'social' science disciplines in marine environmental issues. Despite enthusiasm for interdisciplinarity on environmental issues, institutional and disciplinary barriers remain for interdisciplinary working in practice. This paper explores what natural and social scientists need from each other for more effective impact assessment in the marine environment. We reflect on collaboration between natural- (especially marine biology) and social scientists (especially environmental sociology) researching the Tomakomai CCS Demonstration Project in Japan; including subsequent expansion of the research team and wider evaluation of project outcomes. We identify two areas of mutual support: community and stakeholder engagement on marine monitoring; and identification of points in regulatory/policy processes where qualitative findings may gain traction alongside quantitative results. We suggest interdisciplinary collaboration for marine environmental research could be helped by making time to learn from each other within projects; and by working together more closely in the field.

KEYWORDS: impact assessment; interdisciplinarity; marine social science; sub-seabed carbon dioxide storage

1. Introduction

This paper proposes practical principles for how social and natural science disciplines can work collaboratively for effective impact assessment in the marine environment. There is well-documented interest in assessing social as well as environmental impacts of new marine and coastal developments (Mabon et al, 2017; Vanclay, 2012); and in developing more refined impact assessments, deliberative processes and valuation systems (Skorstad et al, 2018). This reflects a broader understanding that attaining resilient and sustainable forms for coastal communities requires attention to both ecological *and* socio-economic elements (e.g. Beatley, 2018). Integrating natural and social science knowledge systems can lead to the refinement of environmental and social impact assessments, in a way that more fully captures the extent to which a new marine development supports the resilience and sustainability of nearby communities. Yet in a marine environment, governance processes are still emerging, and there are limits to what can be known with certainty compared to on land. This adds additional complexity to the already challenging task of linking social and natural science-based knowledge systems. We respond to this challenge through evaluation of crossdisciplinary research into the environmental and social impacts of the Tomakomai carbon capture and storage (CCS) project, a climate change mitigation demonstration project storing carbon dioxide underneath the seabed in Hokkaido, Japan (see e.g. Tanaka et al, 2017); and reflection in relation to insights from other crossdisciplinary marine research in Japan.

2. Linking natural and social science approaches in marine environmental assessment

Before engaging with existing policy and scholarship, it is important to clarify three terms. Yates et al. (2015) explain that *multidisciplinary research* involves researchers in different disciplines working independently or sequentially to address a common goal or problem; *interdisciplinary research* involves working from different disciplinary perspectives to integrate knowledge and address a common goal or problem; and *transdisciplinary research* happens when researchers work jointly to address complex problems from diverse scientific and societal perspectives, altering discipline-specific approaches and focusing on problem solving for the common good. Transdisciplinary research is also more likely to involve co-creation of research problems and knowledge with stakeholders from society and policy (Newton & Elliott, 2016). We use *crossdisciplinary research* as a generic term for work spanning disciplines, in situations where more than one mode of working may exist or where the mode may shift (e.g. from multi- to interdisciplinary) over time. We are primarily concerned with creating the conditions to move from multi- to interdisciplinary research, and laying the groundwork for progressing to transdisciplinary modes of working.

To be clear, we do not mean to treat 'natural science' and 'social science' as single entities. We recognise there is significant difference between how different disciplines, sub-disciplines and methodological schools operate, for instance the distinction between modellers and observers (Steiner et al., 2016). We use the terms 'natural science' and 'social science' as a point of departure for reflection on how researchers working on ecological systems and researchers working on social systems may better collaborate in practice for effective assessment in marine environments.

2.1. The scholarly case for marine interdisciplinary working

In coastal nations, the sea is a key resource for sustainability. Yet conflicting environmental, social and economic concerns may rule out technically viable offshore activities if not addressed appropriately or early (e.g. Kim et al, 2016). Marine environments are difficult to study, giving rise to inevitable uncertainties when assessing the potential effects on the environment of new developments in the sea (Wright et al, 2016). Different people will interpret the meaning of these uncertainties differently depending on their social and political standpoint (e.g. Ferguson, Solo-Gabriele, & Mena, 2020). Moreover, governance processes such as zoning and planning are not necessarily as well developed in a marine context as they are on land (Soukissian et al., 2017). Nonetheless, the prominence of marine environmental regulations with high degree of consultation, for example the use of local stakeholder panels to drive proposals for Marine Protected Areas in the UK, is increasing (Newton & Elliott, 2016). It is recognised that there is a need to integrate different data sources, both qualitative and quantitative, for effective marine monitoring (Addison et al, 2018). Deliberative approaches have been proposed as a way to bring local knowledge of long-term marine environmental changes and use of marine resources into environmental impact assessments, for example devolving decisions based on impact assessment in the marine environment to the public or their representatives (Benham & Hussey, 2018).

The additional complexities and regulatory uncertainties when undertaking impact assessment in a marine environment are coupled with a turn towards more participatory modes of environmental governance and impact assessment in a number of national contexts including (but not limited to) Scotland (Roberts & Escobar, 2015); Taiwan (Fan, 2020); and Japan (Mikami, 2015). As such, the need for crossdisciplinary working is perhaps even more pronounced for marine environmental issues than on land. These trends also reflect a turn in sustainability research towards integration and implementation of different knowledge systems for researching complex problems (Bammer, 2013; Wiek, Withycombe, & Redman, 2011). Newton & Elliott (2016) chart a move from multi- to inter- to transdisciplinary research in marine environmental management, which increasingly relies on links between science, society and policy from the outset of the research.

However, integration of different types of knowledge may be limited by the physical time and budgetary constraints of project-based research, or by misunderstanding or even distrust of different ways of producing knowledge (Teel et al., 2018). The root of this distance may lie in ontological, epistemological and methodological differences between natural sciences and social sciences (especially for qualitative research) and the difference in the nature of knowledge obtained by different approaches. Natural sciences tend to pursue objective, universal or logical knowledge; whereas in social sciences, especially qualitative research, reality is theorised from the discourses and experiences of people, an approach known as social constructivism. If left unchecked, these different interpretations of what is real (ontology) and what constitutes valid knowledge (epistemology) can reinforce a 'division of labour' between natural and social sciences in environmental risk research, inhibiting the possibility to understand the links between risk calculation, social action and the material outcomes of risk (Wong & Lockie, 2018).

2.2. Institutional and policy landscape for interdisciplinary marine research

On one hand, institutional factors can discourage researchers, especially earlier in their careers, from interdisciplinary working. The British Academy (2016) review into interdisciplinarity identifies pragmatic pressure for academics to work and publish in their disciplinary 'home', which may dissuade researchers from more experimental or risky forms of interdisciplinary collaboration. National assessments of research quality, which in turn can influence the levels of funding institutions receive, may be driven by traditional disciplinary structures (Copley, 2018). Regulators and funders may want specific types of data to meet environmental assessment and monitoring regulations (Wright et al., 2016) rather than more 'experimental' transdisciplinary approaches. This might explain why social science is still often included in impact assessment-type processes as an afterthought – or viewed as public engagement/communication – rather than as a more integral part of the research process (Mabon et al, 2015). Indeed, for monitoring, evaluation and reporting for marine issues, Addison et al (2018: 950) hold that "collaboration is key […]; (t)o facilitate the transfer of technical expertise and information, newer modes of interdisciplinary collaboration and knowledge exchange are required." Whilst acknowledgement of interdisciplinary collaboration is welcomed here, there is arguably an underlying assumption that interdisciplinary working serves to 'transfer' techno-scientific knowledge to the social domain, as opposed to a more iterative process. Liu et al (2018), assessing the views of EIA commissioners for desalination projects in Taiwan, see an entrenched need to present 'impartial' data to 'convince' stakeholders, and an aversion to long, drawn-out assessment processes which delay industrial development. Wright et al (2016) argue that the quality and extent of societal consideration in marine impact assessment remains at the mercy of jurisdiction and project.

On the other hand, research funders are placing increasing emphasis on the early and meaningful integration of different knowledge systems. In addition to disciplinary excellence, national research quality assessments evaluate societal impact from research (e.g. Copley, 2018). The Belmont Forum, an international partnership of funding organisations supporting research into global environmental change, expects in its assessment criteria that projects will foster inter- and transdisciplinary working across scientific disciplines, especially between natural and social sciences (Belmont Forum, 2016). UK Research and Innovation's Sustainable Management of UK Marine Resources programme, launched in 2020, requires applicants to explicitly state how they will facilitate a 'step change' in interdisciplinary working through their projects. More broadly, the need for interdisciplinary working is reflected in the enthusiastic adoption of the responsible research and innovation (RRI) agenda by funders at national (EPSRC, n.d.) and international (RRI Tools, n.d.) levels. RRI works to ensure that technology serves society and to mitigate against technologies reaching deployment stage that are societally unacceptable, through research design that feeds social science into technical research and development processes from an early stage (e.g. Stilgoe, Owen, & Macnaghten, 2013). RRI is likely to become increasingly important for new marine innovations such as offshore CCS, deep-sea mining and larger-scale renewables, due to the uncertainty, broad spatial and temporal reach, and potential for profound societal impacts associated with these technologies.

2.3. Contribution of the paper

The above sections illustrate that whilst there is growing recognition of the necessity of interdisciplinary working from researchers, policymakers, regulators and funders, barriers remain when it comes to putting interdisciplinary research into practice. The purpose of this paper is therefore to work through these complexities and offer practical insights for better connection between knowledge systems in marine environmental assessment. Given the social and environmental complexities of coastal and marine environments, better linkage between environmental and social domains at the assessment stage may provide a more nuanced evidence base to support decisions, and in turn lead to outcomes that support both the ecological and social sustainability and resilience of communities close to new marine developments. We recognise that the need to meet regulatory requirements for data collection and reporting may make more radical forms of ‘interdisciplinary’ working difficult in an applied context. What we therefore aim for is an incremental approach to interdisciplinary working for marine environmental assessment, one that respects existing differences and strengths but tries to take advantage of opportunities for natural and social sciences to strengthen each other’s work and thus provide better impact assessment for society. We illustrate what such interdisciplinary working can look like in practice through reflection on collaborative research for a specific case study.

3. The Tomakomai CCS Demonstration Project and background to collaboration

3.1. Background to Tomakomai CCS Demonstration Project

The Tomakomai CCS Demonstration Project is Japan's largest demonstration of carbon dioxide capture and storage to date, and among the first integrated CCS projects utilising offshore storage globally. CO_2 is captured from processes within an oil- and gas refinery, and injected from an on-land injection site into two sub-seabed formations under Tomakomai Bay via a well drilled directionally beneath the seabed. Injection commenced in 2016 and concluded in 2019, after 300,000 tonnes of CO_2 were injected. Post-injection monitoring will continue at the storage site for the near future.

Several factors make the Tomakomai CCS Demonstration Project significant from an integrated natural and social science perspective. First, unlike many other CCS projects globally, the project is adjacent to a large urban area in Tomakomai City in Hokkaido, which has a population of around 160,000. Second, Tomakomai Bay is also a site for a Sakhalin surf clam fishery. Prior to the commencement of injection and during the operation of the project, local fisheries cooperatives had expressed concern – fuelled by previous negative experiences with industrial activity – about potential effects of CO_2 storage/leakage and associated surveying activity on fish stocks. Third, during the course of operation, the area surrounding Tomakomai had two large earthquakes over winter-spring 2018-19. While an expert panel concluded there was no relation between CO_2 injection and the earthquakes and no evidence of leakage (Japan CCS Company, 2018), the fact that the epicentre of both earthquakes was 20km from the injection point received significant attention on social media.

3.2. Background to collaboration

This paper reflects on collaborative research into the environmental and social impacts of the Tomakomai CCS Demonstration Project. One important distinction to note is that whereas the marine environmental monitoring research carried out by the team has been required by law for environmental impact assessments and for storage and injection permitting – and has fed into regulatory decisions – the social science research has not been undertaken as part of any formal 'social impact assessment', has not fed into any regulatory or policy decisions in Japan, and has not been conducted by or for the operator. In other words, the social science research is primarily a piece of applied academic research. Nonetheless, findings from social science research have been fed back to the project operator, to relevant government departments, and to local authorities in Tomakomai across the span of the CCS project's development and operation.

During the project construction phase (pre-2016), research team members worked separately on different aspects of the project. Marine biology researchers, through the Research Institute of Innovative Technology for the Earth (RITE) and the Marine Ecology Research Institute (MERI), conducted baseline surveys (observation of physical, chemical and biological aspects of seawater and sediment) to support the environmental impact assessment and injection and storage permit applications. More specifically, physical aspects included seawater current and sediment grain size compositions; chemical aspects included concentrations of carbon dioxide and oxygen in seawater and sediment pore water; and biological aspects included species composition and biomass, from microorganisms (e.g. plankton) to macroorganisms (e.g. fish) in the seawater and in the sediment. A social science researcher, meanwhile, conducted stakeholder interviews in Tomakomai and Tokyo to understand initial perceptions of and reactions to the CCS project.

From the start of the carbon dioxide injection phase (spring 2016) through to the end of injection in 2020, the natural and social science researchers began working more closely together. The benefit of closer collaboration was identified in the pre-injection phase, when it became apparent that social science expertise could help guide stakeholder engagement for complex technical monitoring data, and also that a sensitive approach and good coordination was required to ensure residents and stakeholders in Tomakomai did not feel over-engaged by different CCS researchers. Accordingly, closer collaboration included a social science researcher undertaking a two-month secondment to one of the natural science-focused research institutions involved in monitoring above the storage site; the core research team working together to interview stakeholders in Tomakomai (with interview campaigns in 2016, 2017 and 2020); and expansion of the research to include documentary and archival research to understand environmental history and climate change responses in Tomakomai more widely (see e.g. Mabon et al., 2017; Mabon, 2020). As outlined in Sections 3 and 4, the research team were motivated to work more closely together to access key and/or hard to reach stakeholders (e.g. fishers), to understand communication needs and strategies for scientific monitoring data, and also to develop broader interdisciplinary research capacity within their institutions.

3.3. Reflection and evaluation

To facilitate reflection and evaluation on interdisciplinary working for marine environmental issues, research relating to the Tomakomai CCS Demonstration Project was included as a case study in a UK-Japan research network into resilience to environmental change for coastal communities from 2019 onwards. The core Tomakomai research team were all members of this UK-Japan network, alongside experts in integrated coastal zone management, science communication and oceanography from Tokyo University of Marine Science and Technology; and human geography from Robert Gordon University in the UK. This paper is hence part of the reflection and evaluation process for the collaborative Tomakomai research, and was jointly written by network members spanning different disciplinary backgrounds.

Two actions to facilitate interdisciplinary dialogue took place. First was small-scale follow-up interview fieldwork in Tomakomai and lab visits, undertaken by an expanded core research team including early-career researchers from the natural and social sciences. This allowed discussion on how different types of knowledge were produced, and on how researchers at an earlier career stage may connect their practice with different ways of working. Second was opening up the Tomakomai process to discussion and scrutiny from the wider network of TUMSAT and RGU researchers, incorporating a broader range of disciplinary backgrounds (e.g. science communication, integrated coastal zone management, oceanography). Workshop-type interaction and subsequent online discussion were held with the aim of formalising learnings from the Tomakomai collaboration and comparing the insights to other marine environmental issues the network had experience with, specifically engagement with fishers during marine monitoring in the Ariake Sea in south-west Japan and transdisciplinary working with fishers on education for sustainable development programmes in Tokyo Bay. The points in Sections 4,5 and 6 reflect the insights gained from these discussions.

4. What social scientists learned during the collaboration

The first learning point from the social science side of the collaboration relates to uncertainty. In the Tomakomai collaboration, the team found that *crossdisciplinary working can help social scientists to know better the grounds on which natural scientists can make claims with certainty, and where uncertainties or unexpected factors remain*. *This in turn can lead to new conceptual insights.* A good example of the benefits of crossdisciplinary collaboration and knowledge exchange concerns the suspension of CO_2 injection at the Tomakomai site in spring 2016 due to detection, during routine monitoring, of seawater CO_2 levels exceeding trigger points. The events at Tomakomai are not the first time there have been claims of potential for leakage from CO_2 storage sites, following allegations made about Weyburn-Midale in Canada in 2011 (Romanak et al., 2014) and the news article in *Nature* about the Sleipner storage site in Norwegian waters in 2013 (Monastersky, 2013) -

both of which turned out to be baseless. Social science research around controversies over possible leaks from CO_2 storage sites has thus far focused on how ‘experts’ and ‘publics’ might have different perceptions of what is meant by risk and uncertainty (e.g. Boyd et al, 2013; Mabon et al, 2015). Nonetheless, in the case of Tomakomai, close working with marine biology colleagues led to a more refined understanding of how monitoring was done. Specifically, through collaboration it was explained that leakage concerns had arisen due to a ‘false positive’, whereby seasonal CO_2 variations during the collection of pre-injection baseline data led to the trigger points for stopping injection being set too low (Romanak & Bomse, 2020). This insight allowed the social scientists in the research team to go beyond thinking of CCS environmental monitoring in terms of different social constructions of risk and uncertainty, and instead think in more refined ways about what an ‘abnormal’ change in the marine environment means in the context of climate change where the background environment may be changing constantly in more pronounced and unpredictable ways than before. As well as giving the social science team members a richer understanding of their colleagues’ research processes, collaboration hence opened up the possibility for new and richer conceptual social science insights to emerge.

The second learning point is that *collaboration with natural science colleagues can encourage social scientists to articulate their approach to research to different audiences, and open pathways to influencing existing assessment processes.* There is some recognition in environmental science research of different forms of knowledge, in particular acknowledging that qualitative approaches (e.g. interviewing, narrative analysis of documents) produce valid scientific insights if undertaken rigorously (Teel et al., 2018). But it is also true that regulators and operators need measurable and quantifiable, or at least systematic, assessments of risk and impact on which to base decisions. In this regard, natural science colleagues may be more familiar contributing to environmental assessment processes, and can potentially give insight into points at which social science insights might be able to feed in. In the Tomakomai case, the connections that natural science team members (and their institutions) had through assessment and monitoring gave the social science researchers an opportunity to share their research methodology and findings with the project operator, regulatory bodies in Japan, the wider environmental assessment community in Japan (via professional connections), and the international CCS monitoring research and practice community via invitation to join an IEAGHG Environment and Monitoring workshop (IEAGHG, 2020). Presenting social science work to such diverse audiences, however, also pushed social science researchers to reflect on the need to justify the rigour (as opposed to validity, reliability, and transferability) of their research, and to reflect on policy and practice implications as well as contributions to academic theory.

Third and related, *whilst social science disciplines are most readily associated with understanding the human dimensions of environmental issues, it is often colleagues doing marine observational work who will have the first contact with stakeholders and 'the community' in a project*. In the Tomakomai collaboration, marine environmental monitoring activities commenced many months before the social science research, and involved marine biology researchers visiting Tomakomai regularly to conduct sampling. Marine monitoring of this nature entailed extensive face-to-face engagement with local fishers (who provided boats for surveying) and gaining consent from key stakeholders in Tomakomai such as the local government, port authority and coastguard. From a social science point of view, fishers and fisheries cooperatives are key stakeholders for marine environmental issues. This is especially so in Japan, where fisheries are highly culturally significant and fishers hold political power in marine environmental issues. Yet the views of fishers and fisheries cooperatives have been shown globally to be hard to access due to, for example, previous negative experiences with or misperceptions from authority (Nightingale, 2013). The good relationships established by natural scientists during the survey and monitoring work in Tomakomai helped to build conditions of trust to facilitate research interviews with not only fishers, but also the port authority, local government, and others. As elaborated in Section 6, drawing on existing good relations within a multi-disciplinary research team to facilitate field-based social science research may be especially valuable in contexts where there is a sensitivity in the community towards ‘outsiders’ or where stakeholders may feel over-engaged.

Fourth, across the collaboration it became apparent that *natural scientists also interact with people while doing research in the marine environment, and can give their social science colleagues hints and pointers based on what they hear*. As above, marine monitoring involves cooperation with fishers, who hire out their boats to allow scientists to conduct survey and monitoring work. During travel to and from the survey sites, however, informal conversations between fishers and marine biologists yielded valuable insights into how fishers experienced a changing environment (e.g. changes in size or species of fish caught) or what their daily life was like as fishers. As long as such insights are collated and processed ethically, for example by being transparent with fishers that their comments may be noted, maintaining anonymity when writing up notes, and not sharing notes publicly or circulating beyond immediate research team members, these conversations and anecdotes can be a valuable source of information for social scientists to follow up during fieldwork. Indeed, elsewhere in Japan, regional government fisheries departments collate information and stories that their extension officers (staff members working as intermediaries between research and practice, who help fishers in their decision-making through regular face-to-face interaction) hear during informal conversations with fishers, and circulate these internally among their office-based colleagues (personal communication, Fukushima Prefecture Fisheries Section, 27 January 2020).

Fifth and final, during evaluation of the collaboration it became apparent that *social science techniques for collecting research data with publics and stakeholders, i.e. techniques used to build rapport or stimulate discussion, can also be used to facilitate dialogue within an inter- and transdisciplinary research team* to understand overlaps and possible synergies between knowledge systems. Some of the wider project team members have a long-running transdisciplinary partnership on Education for Sustainable Development in Tokyo Bay. As part of these activities, they held a 'fish café,' where researchers, fishers, and residents met to learn and talk about fisheries resource management. To introduce inter- and transdisciplinary working to the participants, who were new to the idea, participants were told to think of their knowledge in terms of a flashlight which could shine light on one part of a single sea event. Different scientific knowledges (in the case of the science café, chemical oceanography and resource management) could be imagined as flashlights casting light on a common wavelength of 'scientific knowledge', each of which illuminated different areas of specialisation. Fishers' knowledge of their own fishery could be imagined as a flashlight on a slightly different wavelength of 'knowledge of experience', casting a broad beam spanning multiple academic disciplines. Questions from participants could be thought of as more precise 'laser pointers', highlighting problems and areas for further enquiry. Thinking in this way allowed areas of common ground for inter- and transdisciplinary working, boundaries to knowledge, and gaps where new knowledge was required to be more easily envisaged (Kawabe et al, 2013). In a transdisciplinary partnership, a thought exercise of this nature provides a heuristic to understand where different knowledge systems can overlap, and where potential points of contention or remaining unknowns may lie. Especially if developed further into graphics and visualisations, heuristic approaches like this can be a useful first step in understanding the composition of an inter- or transdisciplinary team prior to the commencement of impact assessment.

5. What natural scientists learned during the project about social science requirements

The first learning from the natural science team is that *scientists, residents, stakeholders and regulators can have very different understandings of the speed at which research into the marine environment ought to happen.* This learning similarly arises from the 'false alarm' over potential leakage from the sub-seabed storage site in 2016. In the Tomakomai case, based on the seawater chemistry survey, if the value of carbon dioxide exceeds the standard limit, which is obtained from the relationship between carbon dioxide and oxygen in seawater, CO_2 leakage can be suspected and injection must be suspended (Tanaka, 2018). In this situation, more detailed monitoring of seawater quality is required to ascertain whether there is leakage. However, the detailed survey was conducted one month after the concern over leakage, due the need to complete marine insurance procedures and confirm the survey from the Japanese Ministry of the Environment. In the meantime, the marine environment changed significantly, meaning that it became much harder to understand whether the seawater samples exceeded the standard limit due to carbon dioxide leakage or natural environmental fluctuations. Moreover, residents and stakeholders in Tomakomai – especially fishers – had concerns over the potential for leakage and wanted to know results quickly. In sum, the regulations for emergency monitoring did not cope with demand from residents and fishers, hence there is (a) need to know at the outset of the project what local people and fishers expect from the process; (b) a need for faster processes to allow surveys to happen immediately when an abnormality is detected; and (c) an imperative to manage public and stakeholder expectations about how fast scientific results can be obtained. In all three of these areas, greater cooperation with social science researchers from the start of the project could have helped to develop an anticipatory approach to managing stakeholder and societal engagement on suspected leakage, rather than a reactionary approach.

The second learning is that *scientists themselves, when working in the field, may need to be able to act as ad-hoc communicators with the community and with stakeholders – and can in fact be the most trusted communicators for a project*. Linking back to Section 4, some fishers who talked with the marine biologists informally during the survey did not know much about the project. One fisher misunderstood that toxic substances were injected in the seabed. The scientists explained that the project is injecting CO_2, and that the survey was being conducted to confirm CO_2 is not leaking. The fisher was reassured about the project. However, both the government and operators had already explained the contents of the project, engaged with the fisheries cooperatives and explained the project to fishers, yet some fishers still had misunderstandings about CO_2 storage. This may be due to excessive distrust and anxiety about the project. In other words, extensive technical information communicated top-down from the organisations responsible for implementing the project was not in itself reaching fishers. Project scientists hence realised their role was not only to predict, investigate and evaluate the risks of the project, but more also to communicate this information accurately and effectively to residents and stakeholders.

A member of the broader project team had a different experience from a research project in the Ariake Sea in south-west Japan. The research team in that case was heavily geared towards engineering, with only limited social science input. Many fishers could not understand what the engineering scientists said, and as a result, fishers felt that the research could not provide the information they needed. On reflection, it was felt that if social scientists had been involved from the outset of the project to build the research team's understanding of the local context and the communication strategies which may be appropriate, engagement with fishers may have been more effective.

Two questions which arise are thus (a) how to understand preferred modes of communication and engagement for key stakeholders, especially groups such as fishers who may prefer more informal modes of engagement; and (b) how to understand who is trusted to communicate with such stakeholder groups, and ensure that these people are trained and resourced to undertake communication. Both are areas into which social science research techniques can yield insight. Indeed, as per previous work by the wider project team on fisheries elsewhere in Japan (Mabon & Kawabe, 2015), consideration of the relations within a community can illustrate that 'trusted' communicators may not be people who have communications and engagement in their formal job remit.

The third learning is that *even doing scientific research in a community can have effects on residents and stakeholders*. Four years since after survey started, it was clear that the number of fishers who can assist in the survey by hiring out their boat and crew was increasing every year. On one hand, this is evidence that distrust of the project is decreasing and that fishers are more willing to engage with researchers. However, as doing survey work is a good source of income for fishers, the fisheries cooperative in Tomakomai has started to express concern that some fishers prioritise surveying rather than fishing. The natural science team members hence realised a need to be careful when planning surveys (e.g. over-surveying and excessively high charter fees) so as not to hinder the fishers' main work. Relating to the points raised in Section 4 about the sensitive and ethical handling of informal information received from fishers, there may thus be value in basic ethics training for natural science researchers as preparation for handling situations that may arise in the field.

Whilst it is good practice to use local boats for surveying, one should know beforehand that this can have detrimental effects if not done properly and be aware of the local context. In Tomakomai, the CCS project happens against a background context of fishing catch decreasing and dependency of fishers on other incomes. Again, a member of the wider project team reported a similar situation around involving fishers in field monitoring in the Ariake Sea. In this case too, fishers were able to supplement their income by participating in monitoring. However, in the Ariake case, the total income could not cover the decrease in fisheries catch, and fishers still aimed for the recovery of fisheries. As such, whilst activities such as supporting scientific surveys can diversity fishers' income sources, there is a need to exercise caution so as to not inadvertently create dependency among fishers on surveying work. This is an area where both projects' natural scientists, on reflection, felt they could have benefitted from earlier social science collaboration to understand the local situation and prepare for unexpected effects arising from their survey research.

6. Discussion

6.1. On what grounds can we claim a collaboration is successful, and why?

Before turning to the scholarly contributions of our findings, we address two questions: (a) on what grounds can we consider the Tomakomai collaboration to be successful; and (b) what enabled the elements of collaboration that were successful? Academically, 'success' is reflected in the way the collaboration illustrated examples of best practice outlined in extant literature on interdisciplinary working for marine environmental issues. Specifically, mutual learning (Vanderlinden et al., 2020); systems thinking and integration of normative issues (Wiek et al., 2011); and a tentative move towards linking natural and social science with policy and practice across the research process (Newton & Elliott, 2016). To date, examples of integrated practice like this for offshore CO_2 storage are limited. Practically too, 'success' may be illustrated by the engagement of the operator and regulator with not only the environmental science findings of the collaboration, but also the social science outputs (via training workshops, seminars, and face-to-face briefings). Table 1 summarises factors identified during discussion and reflection between team members (and insights from wider network members) that made the collaboration successful, and also identifies potential barriers to others following similar practice.

Table 1: factors contributing to successful collaboration

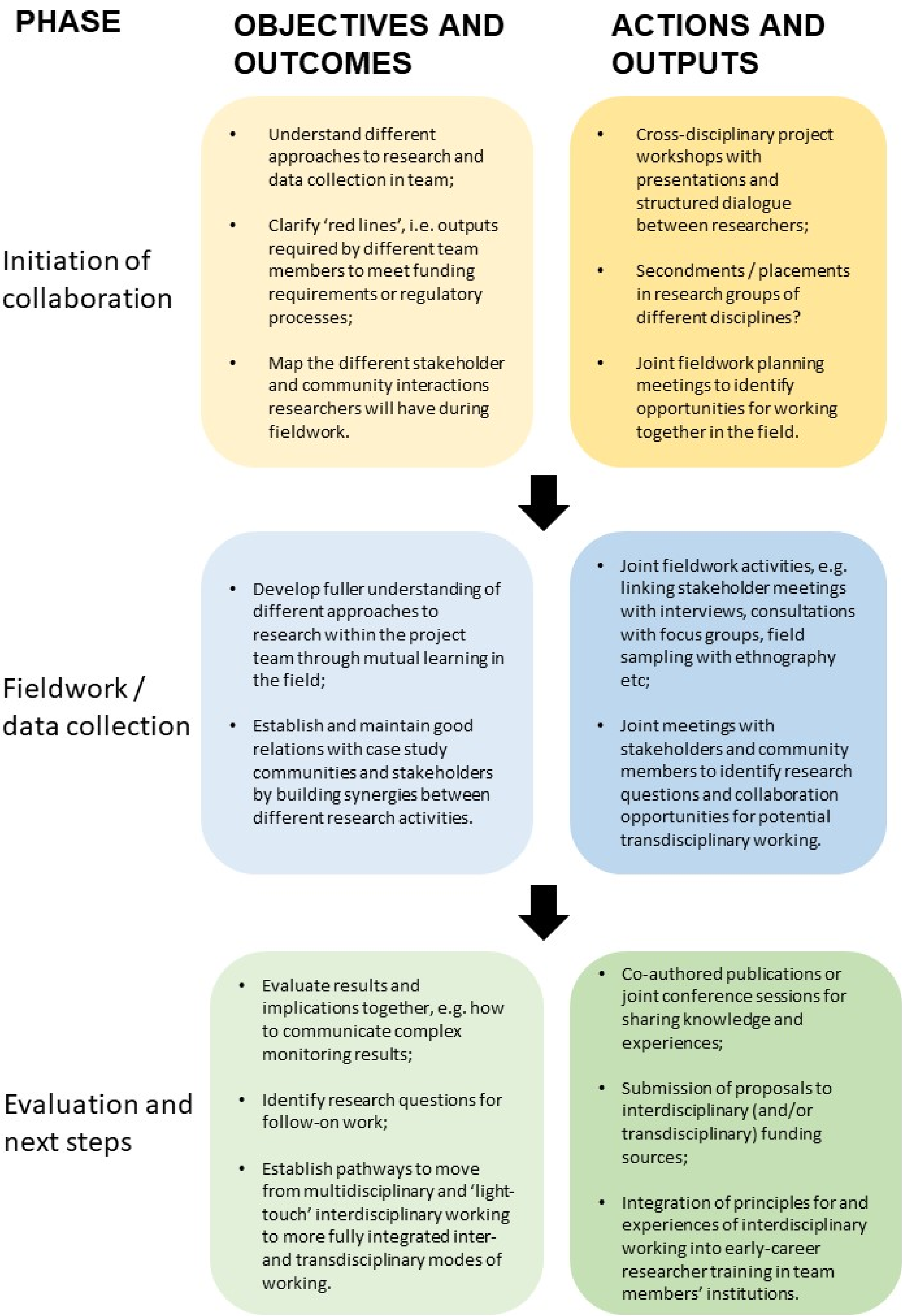
Factors contributing to success	**What enabled this factor?**	**What may be a barrier to others following similar practice?**	**What could help to overcome these barriers?**
Openness of individual research team members to engaging with different ways of knowing and considering how this may be integrated in their own practice.	Background and experience in applied research at the science-policy-practice interface among team members; institutional structures facilitating cross-disciplinary	Pressure – especially among early-career researchers – to produce discipline-specific outputs (British Academy, 2016) focusing on conceptual	Structured opportunities (such as training workshops) for developing competences at individual level for interdisciplinary working (e.g. Wiek et al., 2011) integrated in

	exchange in scholarly practice.	contributions in own disciplinary space.	researcher training; continuing trend towards interdisciplinary funding calls (e.g. Belmont Forum).
Pathways for social science-focused project outputs to feed into policy and practice spheres for marine environmental assessment, which remain natural science-focused.	Sensitivity to and dialogue around different disciplinary norms and expectations regarding collaboration with industry and national government.	Reluctance to engage with private sector or governmental actors due to personal or disciplinary norms, and/or concerns over impartiality.	Codes of conduct developed at project or funder level to clarify and limit role of industry in projects (e.g. ethics principles for ReFINE shale gas research (Davies & Herringshaw, 2016)).
Sound understanding of the logic of different research methods, leading to better understanding across research team.	Collaborative working 'in the field' (e.g. marine biologists joining social scientists for interviews and archive work; lab visits from social scientists).	Time and budgetary constraints of project funding, need to focus on project-specific research and outputs rather than experimentation and improvisation.	Flexible and substantial research funding – including staff time/overheads and costs for pilot research, not just knowledge exchange workshops – to allow meaningful development of interdisciplinary networks before committing to larger projects.
Openness to external critical scrutiny and to expansion of the research team to include new perspectives (e.g. coastal zone management) as part of an ongoing process of evaluation across the project duration.	Integrating Tomakomai project team within wider research project, and using it as a case study for evaluating interdisciplinary marine working.	Development of closed epistemic communities resistant to external critique and seeking to control their influence over science-policy interface (Stephens, Hansson, Liu, de Coninck, & Vajjhala, 2011).	Encouragement of inclusion of structured reflection and evaluation processes (e.g. Vanderlinden et al., 2020) to reflect on relations with different actors and avoid 'group think'.

6.2. How does our reflection advance interdisciplinary research for marine environmental assessment?

Figure 1 synthesises the learnings from the Tomakomai CCS collaboration, and lays out possible steps towards the incremental approach to interdisciplinary working we proposed at the outset of the paper. In addition, we offer three overarching insights which link back to the Introduction and speak to the conceptual and practical implications of interdisciplinary research for marine environmental assessment.

Figure 1: incremental approach towards interdisciplinary working for marine environmental assessment


PHASE
OBJECTIVES AND OUTCOMES
ACTIONS AND OUTPUTS
Initiation of collaboration
• Understand different approaches to research and data collection in team;
• Clarify 'red lines', i.e. outputs required by different team members to meet funding requirements or regulatory processes;
• Map the different stakeholder and community interactions researchers will have during fieldwork.
• Cross-disciplinary project workshops with presentations and structured dialogue between researchers;
• Secondments / placements in research groups of different disciplines?
• Joint fieldwork planning meetings to identify opportunities for working together in the field.
Fieldwork / data collection
• Develop fuller understanding of different approaches to research within the project team through mutual learning in the field;
• Establish and maintain good relations with case study communities and stakeholders by building synergies between different research activities.
• Joint fieldwork activities, e.g. linking stakeholder meetings with interviews, consultations with focus groups, field sampling with ethnography etc;
• Joint meetings with stakeholders and community members to identify research questions and collaboration opportunities for potential transdisciplinary working.
Evaluation and next steps
• Evaluate results and implications together, e.g. how to communicate complex monitoring results;
• Identify research questions for follow-on work;
• Establish pathways to move from multidisciplinary and 'light-touch' interdisciplinary working to more fully integrated inter- and transdisciplinary modes of working.
• Co-authored publications or joint conference sessions for sharing knowledge and experiences;
• Submission of proposals to interdisciplinary (and/or transdisciplinary) funding sources;
• Integration of principles for and experiences of interdisciplinary working into early-career researcher training in team members' institutions.

First, our experiences speak to the challenge of integrating different knowledge systems for researching complex environmental problems (Bammer, 2013; Yates et al., 2015); yet still being able to influence policy and practice spheres, where regulators and policy-makers may expect research outputs to fit within existing frameworks (Addison et al., 2018; Newton & Elliott, 2016). Reconciling this tension is especially difficult when some researchers come into a collaboration from an academic tradition (closer to social science) that views environmental risk as an outcome of people's perceptions and beliefs; whereas others come from an academic tradition (closer to natural science) that approaches risks as something that can be assessed objectively and impartially (Wong & Lockie, 2018).

The Tomakomai collaboration offered insights into what may help scholars with different interpretations of what constitutes valid knowledge to work together for marine environmental issues with a practical or policy outcome, especially around bridging different views on how environmental risk can be understood and assessed. Key was making time for mutual learning between natural sciences (here marine biology) and social sciences (in this case environmental sociology) across the project process, through activities such as structured team workshops, lab visits, cooperative field work, and attending conferences/workshops from each other's fields. Similarly, in a reflection on coastal research spanning case studies in Greenland, Russia, Canada, France, Senegal, India and others, Vanderlinden et al. (2020) argue that an emphasis on mutual learning is important for successful transdisciplinary collaboration. Such mutual learning, which Vanderlinden et al call 'sensemaking', likewise involved collaboration across the scientific process, including joint analysis, discussion and sharing of scientific findings. For both our Tomakomai experience and that of Vanderlinden et al., such activities help to give a more nuanced understanding of how data is collected, what is known with certainty, where remaining uncertainties lie and how these are interpreted, and how to communicate this uncertainty to non-experts.

Second, our findings reinforce the value and benefit of close collaboration across disciplines, not only at the research problem formation stage – which has been well discussed in existing thought on inter- and transdisciplinary working (British Academy, 2016; Wiek et al., 2011) – but also during field working. Sections 4 and 5 show that in the Tomakomai case at least, observation-based environmental research involves significant interaction with publics and key stakeholders in the marine environment such as fishers. Closer coordination during field campaigns between natural and social science project members may help to reduce research fatigue for community members who may feel 'over-researched' (Clark, 2008) and develop more finely-tuned research and engagement strategies. Coordination in the field may be especially important where the issue being researched is sensitive or controversial issue, and where stakeholders and residents may be apprehensive about social science researchers coming into the community from outside. A similar mode of collaboration proved successful for social science research around the QICS experimental CO_2 release in Scotland, a field trial of a new and unfamiliar technology where the project team were cautious not to make community feel they too were being 'measured' as part of the experiment (Mabon et al., 2015). It may even be possible or desirable for a research team to work with the community and stakeholders to actively involve them in the research process (e.g. involvement in doing social impact assessments and environmental data collection) as a way to understand how to minimize the negative impacts of development on their communities (Franks, 2012).

Coordination in the field can also help to understand ways in which research brings positive benefits to a local community, and identify and minimise potential ethical issues. Not every marine survey will utilise local fishers' boats as happened in Tomakomai. However, the positive and negative implications of chartering fishers' vessels illustrates that "even the act of doing a social or environmental impact assessment can create social impacts" (Vanclay, 2012: 152). Social sciences are well-versed in thinking through such ethical implications across the whole span of a project (Hind et al., 2015). Research teams would thus do well to work together to think through how their field activities may be shaped to bring benefit to communities (e.g. involving local researchers within projects where possible, using local businesses for accommodation and meals), and limit negative impacts (e.g. not raising expectations about projects or creating dependency on income from visiting researchers).

Third, our experiences indicate that much of the success of inter- and transdisciplinary working comes down to the personalities and qualities of the people involved, irrespective of their field of expertise. Across all the case studies presented in the paper, the motivation to initiate and maintain interdisciplinary working came as much from the personal enthusiasm and commitment of the researchers involved as it did from institutional or policy drivers. The theories and methods of social science can of course help to develop effective risk communication strategies and facilitate dialogue within research teams. But the individual competences such as systems thinking capability and interpersonal skills that Wiek et al. (2011) see as fundamental for interdisciplinary working may be developed by anyone, regardless of disciplinary background. Capacity-building to facilitate interdisciplinary marine research (McKinley, Acott, & Yates, 2020) may therefore benefit from paying attention not only to the nature of different knowledge systems and how they work together, but also to developing skill sets for interdisciplinary working in researchers themselves.

7. Conclusions

We return to the title of this paper – what natural and social scientists need from each other for effective marine environmental assessment. Dialogue on epistemology and methodology at the research problem formation stage, and constant reflection and evaluation across the project span, fits well with research funders' increasing interest in meaningful and tangible actions to integrate different disciplines within research projects. Researchers themselves are also becoming ever more aware of the value of interdisciplinary approaches in generating richer understandings of the marine environment. As such, principles for interdisciplinary working are likely to have value to marine research beyond the immediate benefit of more nuanced impact assessment for marine issues. We thus propose the following as practical action points where social and natural scientists may support each other's research.

What social scientists need from natural scientists:

- Better understanding of physical environmental changes – and what can be known with certainty – to nuance constructivist understandings of environmental risk;
- Access to forums and spaces where marine environmental assessment and regulation takes place, with the opportunity to justify and demonstrate the insights from rigorous social science research;
- Support in accessing key stakeholders within communities, especially for contentious or sensitive projects;
- Insights into informal and anecdotal information on environmental change gleaned during field sampling and/or survey work.

What natural scientists need from social scientists:

- An understanding of what exactly stakeholders and communities need/want to know from environmental monitoring and assessment, and at what speed;
- How residents and stakeholders want to be engaged and who they trust for communication;
- What the unintended consequences might be on a community from doing impact assessment work. The Tomakomai and Ariake Sea cases show this is true for environmental assessment and monitoring as well as for social science research, due to the necessity of interacting with stakeholders to obtain consents and access.

Building on the current groundswell of work into inter- and transdisciplinary research design, our findings show that greater crossdisciplinary collaboration in the fieldwork phase may lead to richer insights and more comprehensive impact assessment. In particular, greater opportunities for mutual learning on epistemology and methodology within research teams, and greater collaboration in the field, are ways to generate practical benefits from collaborative working. Realising this, however, requires not only openness and patience from researchers themselves, but also support from institutions, research funders and regulators.

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