Improving invasive species management by integrating priorities and contributions of scientists and decision makers

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ABSTRACT

Managing invasive species is a major challenge for society. In the case of newly established invaders, rapid action is key for a successful management. Here, we develop, describe and recommend a three-step transdisciplinary process (the ''butterfly model'') to rapidly initiate action for invasion management. In the framing of a case study, we present results from the first of these steps: assessing priorities and contributions of both scientists and decision makers. Both scientists and decision makers prioritise research on prevention. The available scientific knowledge contributions, however, are publications on impacts rather than prevention of the invasive species. The contribution of scientific knowledge does thus not reflect scientists' perception of what is essentially needed. We argue that a more objective assessment and transparent communication of not only decision makers' but also scientists' priorities is an essential basis for a successful cooperation. Our three-step model can help achieve objectivity via transdisciplinary communication.

Keywords: Conservation managers, Decision makers, Invasive species, Round goby, Strong objectivity, Transdisciplinary

INTRODUCTION

Invasive species are a major global threat to biodiversity (Sala et al. 2000), and their economic costs have been estimated to be almost 120 billion $/year in the USA (Pimentel et al. 2005) and 12.5 billion EUR/year in Europe (Kettunen et al. 2009). Managing invasive species remains a major challenge because it requires the close cooperation of two key players (Seidl et al. 2013): scientists and decision makers. Traditionally, the scientific community provides a scientifically sound basis for management measures, while decision makers are responsible for the decision about and implementation of management measures. Thus, the main task of scientists is to find causal relationships and publish the results in peer-reviewed papers (Byers et al. 2002), and the main task of decision makers is to decide about management strategies and their implementation (Simberloff 2009). However, for a successful invasive species management strategy, it is necessary to cross these disciplinary boundaries (Heger et al. 2013). A transdisciplinary process allows to reach such a cooperation between scientists and decision makers and ''to overcome the mismatch between knowledge production in academia, on the one hand, and knowledge requests for solving societal problems, on the other'' (Hirsch Hadorn et al. 2008).

This paper aims to evoke a more objective view of scientists' contributions to a transdisciplinary process. Our perspective of a transdisciplinary process is based on the systems perspective. Put forward by Seidl et al. (2013), the systems perspective aims to facilitate a thorough transdisciplinary interaction between science and society by acknowledging and combining different groups' priorities and decision spaces. We adopt this perspective and formulate a practical three-step approach which we term the ''butterfly model''. The goal of our model is to combine the priorities and decision spaces of scientists and decision makers into a joint research paradigm for managing invasive species. Our model's three steps are as follows: firstly an objective assessment of decision makers' and our own (scientists') priorities and contributions to the co-production of knowledge (Step 1); secondly a communication of. this assessment's results to gain mutual understanding between players (Step 2); and finally the establishment of a joint research paradigm based on the mutual appreciation of contributions (Step 3). Following Chalmers (2013), we define a paradigm in the practical sense as such that it coordinates and directs the ''puzzle-solving'' activity of a group.

We specifically emphasize the need to include ourselves in our roles as scientists. Recent applications of the concept of ''strong objectivity'' suggest that a transdisciplinary process greatly benefits from such a reflexivity of scientists about their own standpoint (Rosendahl et al. 2015). Importantly, the objectivity here does not mean a factbased approach as a characteristic of the scientific method. Rather, it is the process of scrutinising our own standpoint as scientists that needs to be more facts-based and more objective. We argue that one major step towards improved objectivity is to achieve more transparency in the communication of our contributions. More directly put, we as scientists should disclose on what basis and priorities our knowledge is built on. In this paper, we exemplify how exactly our three-step approach will play out in reality by means of a topical case study.

Using a case study to demonstrate the first step of a transdisciplinary process

Our case study is a recent fish invasion in the River Rhine (RR) in Switzerland. The RR plays a paramount role socioeconomically in Switzerland. It is the largest river of Switzerland and its catchment comprises 88 % of the country's total area (Fig. 1). Countless restoration efforts have been instated to restore its previously compromised ecosystem health (IKSR 2015, accessed June 24th). Recently, the non-native round goby (*Neogobius melanostomus*) was detected in a Swiss harbour of the RR (Kalchhauser et al. 2013). Round goby is a small (mean total body length around 10 cm) bottom-living fish species native to the Ponto-Caspian region. It is listed as one of Europe's 100 worst invaders and is believed to be a potential threat to native ecosystems (DAISIE 2015, accessed June 24th). An account of its possible impacts on native species can be found in Hirsch et al. (2015). Because iconic freshwater fish species such as the salmon (*Salmo salar*) could potentially be affected, the round goby invasion is a concern amongst societal groups interested in the RR. This is further elaborated upon in Hirsch et al. (2015). In an unpublished survey, we found that a majority of surveyed societal groups associated to the RR, either as hobbyists or professionally, want to preserve the river ecosystem with its variety of ecological functions. An invasive round goby population is a possible threat to this natural value. We therefore assume that the invasion underway actually is a concern to a relevant part of society. Exploring whether and how a round goby invasion management would be in line with the public opinion at large, and whether and how the European strategy on invasive alien species (Genovesi and Shine 2004) or signed conventions such as the Convention on Biodiversity (Secretariat of the Convention on Biological Diversity 2005) make such a management imperative, is beyond the scope of this article.

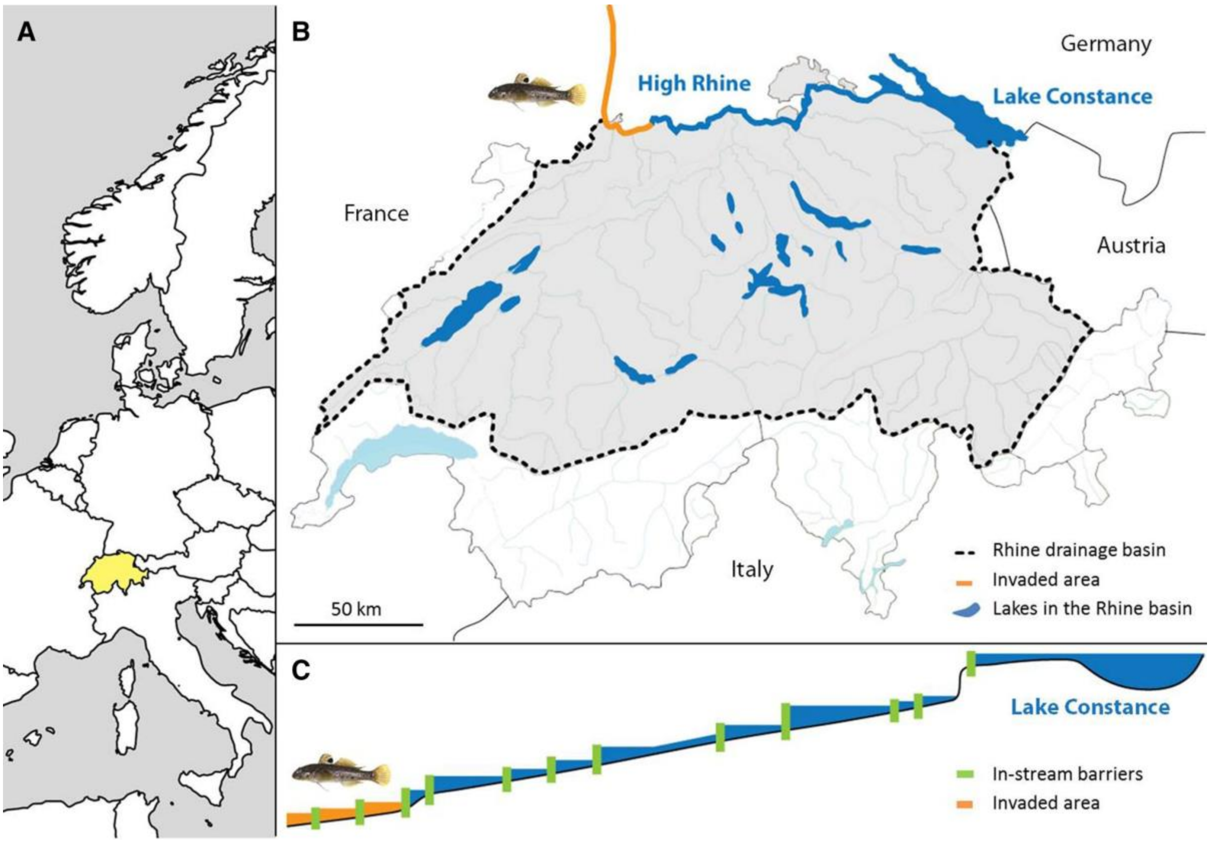

Figure 1: The geographical situation of the recently established round goby population in Switzerland makes a management probable. A, B Round goby (Neogobius melanostomus) was first detected in Switzerland 2012 in the Rhine harbour in Basel. C Gobies are bad swimmers and a series of 12 in-stream barriers (hydropower dams) in the River Rhine (RR) upstream of Basel may prevent the natural dispersal of round gobies further into the RR. However, human recreational activities can aid natural dispersal by translocating invasive

species. For example, each of the instream barriers is crossed by recreational boats that could provide means of transport for round gobies and allow them to disperse further (own manuscript, in review). Further upstream the RR lies Lake Constance, a pre-alpine lake which features socio-economically important recreational and commercial fisheries (Hirsch et al. 2013). Because round gobies are unlikely to naturally disperse into the lake, preventive management is a real possibility, provided that measures to halt the translocation of round gobies are implemented rapidly. If the localised population is not rapidly managed, it will most likely spread and increase its range, making a management less feasible and more expensive (Vander Zanden and Olden 2008).

Because of the special geographic situation, the restricted range of the population, and because round gobies are unlikely to substantially expand their range through natural dispersal (Fig. 1), the chances for success of a rapid management are high. Therefore, in the framing of our case study, we apply our proposed three steps towards a transdisciplinary process for a management of round goby. We follow all three steps as follows:

Step 1: Objective assessment. To assess our own priorities and contributions to the co-production of knowledge as scientists in practice, we asked the following questions:

a.) What are decision makers' and scientists' research priorities concerning the management of round goby in the River Rhine, and do they match?
b.) Are decision makers' and scientists' research priorities reflected in the existing body of scientific knowledge?

We answered these two questions using two approaches: a workshop survey and a quantitative literature review. While surveying decision makers' priorities at a transdisciplinary workshop, we also surveyed scientists' own priorities concerning round goby research. The research priorities of both groups were then compared to scientists' main contribution to the process, i.e. scientific knowledge represented in peer-reviewed papers.

Step 2: Communication. Based on the results of this assessment, we review existing recommendations and conditions that favour a successful communication within a transdisciplinary project. We give specific hints on how a transparent communication in our case study and in general could be implemented.

Step 3: Joint research paradigm. To outline the final step in our model, we combine the results and insights from the first two steps. We propose how the establishment of a joint research paradigm can proceed based on the first two steps. Finally, we discuss how joint research paradigms can be put into practice in the context of species invasions.

METHODS

Workshop survey

Following the human-environment system approach to a transdisciplinary process (Seidl et al. 2013), we started by transparently assessing decision makers' and scientists' contributions to the process. Decision makers, in our context, are not limited to political decision makers, but also include societal decision makers (Secretariat of the Convention on Biological Diversity 2005; Nentwig 2007; Hirsch Hadorn et al. 2008). Thus, decision makers include relevant stakeholders that both hold a stake and have technical experience in the topic, and non-certified socalled ''experience-based experts''. These stakeholders and non-certified experts have a specialist expertise in a field relevant to the case study of round goby and could be divided into two groups: representatives of recreational fisheries and conservation managers. Representatives of recreational fisheries are e.g. fisheries wardens or opinion leaders of local fishing clubs. Conservation managers are local environmental authorities or non-governmental environmental agencies. In contrast to these non-certified ''experience-based experts'', we defined invited scientists from other institutions and ourselves as ''certified experts'' with a specialist expertise in a field relevant to the research. For a detailed discussion of different demarcations between such groups, please refer to Collins and Evans (2002) and Defila and Di Giulio (2015).

The policy and decision-making processes on invasive species in Switzerland can be separated into two levels, the federal level and the cantonal level. At the federal level, there are over-arching policies issued such as the ''Strategy on Invasive Alien Species'' (Federal Office for the Environment Switzerland 2015). At the cantonal level, there are more specific regulations in place (such as the ''Ordinance on the Release of Organisms into the Environment'', Swiss Federal Council 2008) which are followed and enforced by local authorities. In appreciation of this complex decisionmaking structure, we had representatives from both authorities joining the group of decision makers (see above).

Shortly after round goby arrival, we installed yearly decision maker workshops to share the current state of scientific knowledge and to discuss management methods. For the kick-off workshop, we chose a three-phase approach. In the first phase, the participants were informed about the round goby case in the plenum. In the second phase, the participants were allocated to five brainstorming groups consisting of maximum five persons with different backgrounds. In each group, at least one scientist was present. To reach ''strong objectivity'' (sensu Rosendahl et al. 2015), scientists need to openly communicate their role and their standpoint in transdisciplinary research. During the brainstorming process about future round goby management, a set of research priorities evolved. In the last phase, the participants joined again in the plenum and the research priorities from all groups were presented. Following the multi-voting variant, a form of cumulative voting, each participant could allocate five votes to the research areas (Bens 2012). It was possible to allocate several votes to the same area, but not more than three votes. Votes were cast during a workshop break and could be assigned to groups (decision makers and scientists) via group-specific colour codes, but not to individuals.

Literature review

To evaluate how decision makers' and scientists' priorities are reflected in the contributions (i.e. peer-reviewed papers) of the broader scientific community, we performed a systematic quantitative literature review following the PRISMA statement (Moher et al. 2009). This method allows to objectively identify the current state of scientific knowledge (Pickering and Byrne 2014). Because invasive round gobies are well studied in different spatial and temporal scales on both sides of the Atlantic, they provide an ideal case study to assess the traditional contributions of scientists to a transdisciplinary process in the context of invasions.

We carried out four literature searches covering four research priorities that emerged in the workshop: impacts on native species, early detection methods, preventing the spread and control measures. The fifth priority ''costs of management measures'' was covered within the results of prevention and control measures. The literature searches were carried out in the web of knowledge database (http:// webofknowledge.com) using the search terms 'round goby' and 'Neogobius melanostomus', combined with search terms for one of the four priorities. The search terms were separated by Boolean operators 'AND' or 'OR'.

For all four searches, we followed the steps outlined in the PRISMA statement (Moher et al. 2009). In a first step, duplicates were removed. In a second step, papers were screened to identify relevant primary research articles. Only peer-reviewed studies in English were considered. All review articles, books, book chapters and grey literature such as reports were excluded. We acknowledge that nonpeer reviewed publications can be a useful source of information for invasive species management. However, we were primarily interested in an assessment of the role of scientists as a hub for scientific knowledge. In particular, we wanted to make the scientific knowledge contribution to the transdisciplinary process more transparent by scrutinising scientists' prime sources of knowledge: peer-reviewed papers. Despite substantial shortcomings of the peer-review process, it is still the highest standard in science and peer-reviewed papers are compiled in databases that can be mined in a transparent way.

The full text of the remaining peer-reviewed papers was assessed for eligibility (see Table 1 for inclusion criteria). For a paper to be deemed relevant in the category ''impact on native species'', it must provide a quantitative analysis of round goby interactions with other species. These impacts must be measurable, but not necessarily significant (Davidson and

Hewitt 2014; Ojaveer and Kotta 2015). Impacts must be based on results from a field study or laboratory experiments, including e.g. stomach content analysis, stable isotope analysis or behavioural experiments. For a paper to be deemed relevant in the categories ‘‘early detection’’, ‘‘prevention’’ or ‘‘control’’, it must provide basic research towards the measure, including modelling, or a practical application of the measure, either in the laboratory or in the field. Basic research is defined as research towards understanding fundamental processes without the goal of applying the results in a practical context; applied research is conducted with the clear goal of applying the results in a practical context.

The reference lists of relevant papers were screened for additional papers, which entered the same process as papers found in the database. The information of relevant papers in each research area was entered in a personal spreadsheet database (Pickering and Byrne 2014).

Table 1: Inclusion criteria for papers in each research area and resulting search terms

Research area	**Inclusion criteria**	**Search term used**	**Last search carried out on**
Impacts on native species	Quantitative analysis of round goby interactions with other species such as predation, competition for food or shelter and availability of a new prey. Impacts are based on data from field studies or laboratory experiments, including, e.g. stomach content analysis, stable isotope analysis or behavioural experiments	(‘round goby’ OR ‘neogobius melanostomus’) AND (‘diet’ OR ‘predation’ OR ‘prey’ OR ‘competition’ OR ‘impact’ OR ‘effect’)	08/04/2015
Preventing the spread	Basic or applied research on how to prevent the spread of round goby, e.g. modelling of vectors, risk assessments with policy implications	(‘round goby’ OR ‘neogobius melanostomus’) AND (‘prevention’ OR ‘preventive’ OR ‘management’ OR ‘spread’)	05/06/2015
Early detection methods	Basic or applied research on how to detect round goby early, e.g. eDNA, monitoring by anglers	(‘round goby’ OR ‘neogobius melanostomus’) AND (‘eDNA’ OR ‘e-DNA’ OR ‘environmental DNA’	05/06/2015

		OR ‘early detection’ OR ‘monitoring’)	
Control measures	Basic or applied research on how to control round goby, e.g. predatory control, piscicides, physical removal, population modelling	(‘round goby’ OR ‘neogobius melanostomus’) AND (‘control’ OR ‘eradication’ OR ‘management’)	05/06/2015
Costs of measures	Reference to the costs of methods or measures	Directly located in papers of the other four areas	

RESULTS

Workshop survey: Decision makers’ and scientists’ research priorities match

The workshop survey revealed a match of priorities between decision makers and scientists; both prioritise research towards preventing the spread of an establishing invader. The multi-voting process with 13 decision makers and 9 scientists showed that both groups’ first priority is research on preventing the spread of round goby (23.4 and 24.5 % of cast votes, respectively; Fig. 2). Scientists’ next priorities are research about impacts on native species (8.5 %), early detection methods (6.4 %) and control measures (5.3 %). Decision makers’ next priorities are research about control measures (16 %), impacts on native species (7.4 %), early detection methods and costs of management measures (both 4.3 %).

When priorities of the two decision maker groups (recreational fisheries and conservation managers) are analysed separately, some differences between the two groups become apparent: conservation managers are more interested in impacts’ research, early detection and cost of management. However, both groups almost equally prioritise research on the prevention of spread and control measures (Fig. 2).

Literature review: Research contributions and research priorities do not match

The quantitative literature review revealed a mismatch between scientists’ priorities and the current state of published scientific knowledge. The systematic quantitative literature review focussing on the five priority areas showed that most published research results are about impacts of round goby on native species. There seems to be a lack of publications on preventive management options that have received the highest standard of scientific quality control, i.e. peer review (Fig. 2). The systematic quantitative literature review showed that the large majority of peer-reviewed papers (76 %, n = 113) is about round goby impacts on native species. Research results on control measures are presented in 4 % of papers (n = 6), on preventing the spread in 14 % (n = 21) and on early detection methods in 1 % (n = 2). Six papers (4 %) refer in some way to costs of measures.

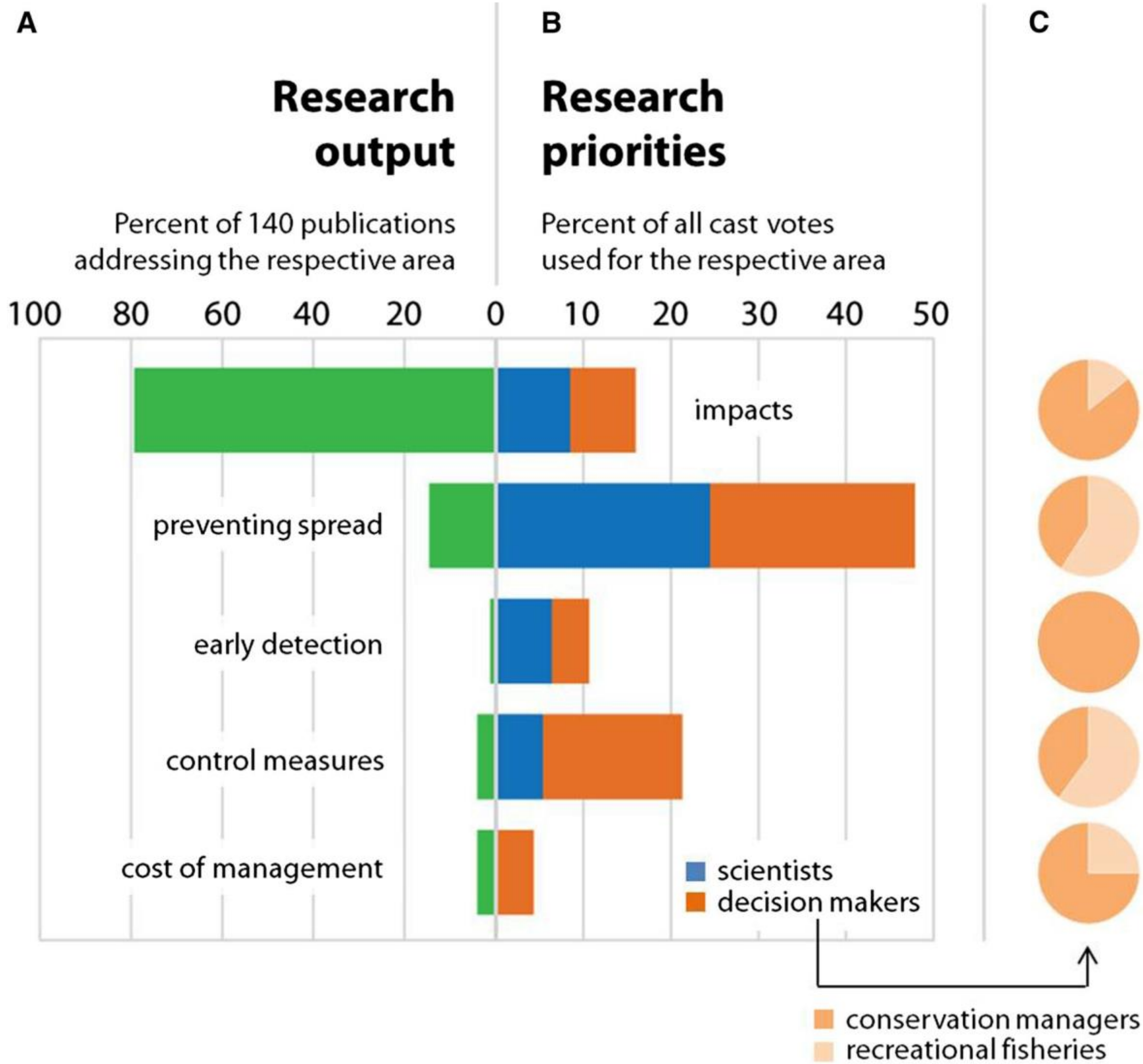

Figure 2: Research contributions and research priorities. A Research contributions represented by peer-reviewed papers identified in the literature review (n = 140) do not match the research priorities of either decision makers or scientists: most research covers impacts of round goby on native species. **B** Research priorities of decision makers (n = 13) and scientists (n = 9) identified in the workshop survey match: both groups prioritise research towards preventing the spread of round goby. **C** Detailed presentation of votes cast by subgroups of decision makers: conservation managers and representatives from the recreational fisheries

DISCUSSION

Our study aimed to evoke an objective view of scientists' research priorities and contributions to the management of an invasive species. To this end, we proposed the butterfly model consisting of three steps, the first of which we tested ''in the field'' by analysing data from a transdisciplinary workshop (Fig. 2). Taking the first step, we objectively assessed scientists' and decision makers' research priorities concerning the management of an invasive species. An objective literature review revealed that the knowledge scientists actually contribute to the process does not match the research they prioritise, whereas both groups' research priorities match. We discuss these findings in detail and present an outlook for steps 2 and 3 in the transdisciplinary process (Fig. 3).

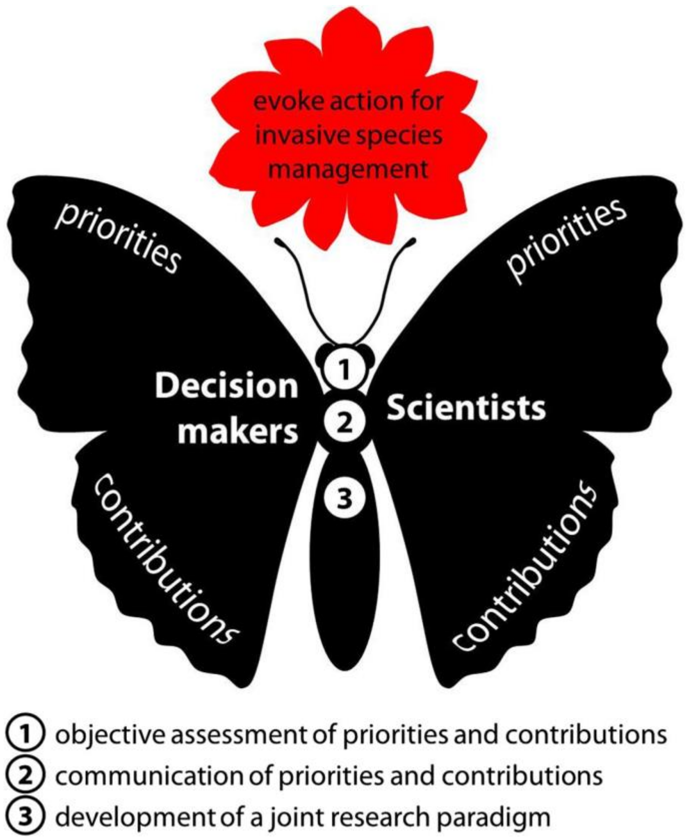

Figure 3: The butterfly model. Decision makers and scientists need to engage in a three-step transdisciplinary process to evoke action for invasive species management

Step 1: Objective assessment

To identify the gap between research priorities and research contributions among or within groups is a fundamental first step of a transdisciplinary process under the concept of strong objectivity. The concept posits that strong objectivity is needed to instigate a fruitful communication between players in and outside academia (Rosendahl et al. 2015). Our literature review revealed that scientists' primary contributions in the form of peer-reviewed papers are insufficient as a knowledge basis for invasive species management: most knowledge is on impacts of round goby and not on its management. We deemed it relevant to further scrutinise the knowledge that scientists actually can contribute to the process, which is knowledge on round goby impacts. To accomplish this, we conducted an in-depth review of publications dealing with round goby impacts alongside our transdisciplinary project. The results are presented and discussed in detail in Hirsch et al. (2015).

From an objective standpoint, the mismatch between priorities and existing knowledge is especially interesting. As evidenced by numerous conventions and statements, the international scientific community views prevention as the ''gold standard'' in invasive species management (Leung et al. 2002; Cook et al. 2007; Keller et al. 2008; Vander Zanden and Olden 2008; Vitule et al. 2009; Simberloff et al. 2013). Within the scientific community, there is a solid knowledge on the fact that acting timely is necessary to prevent the spread of an invasive species. This knowledge is based on empirical studies which have repeatedly shown how effective early action against invasive species can be (Horan et al. 2002; Lockwood et al. 2005; Keller et al. 2008; Vander Zanden et al. 2010; Edelaar and Tella 2012). Despite this agreement on the importance of prevention, there seems to be a lack of studies about scientifically tested, specific and practical prevention measures. The underlying mechanisms behind this discrepancy might be explained by the fact that scientists do not get credit for publishing papers on successful preventive management or even research towards it; vice versa, decision makers are rewarded for managing, not for publishing (Simberloff 2009).

Our finding of a mismatch between scientists' priorities and scientists' contributions to the process of knowledge coproductions has implications for the way we interact with decision makers. One often-mentioned reason why decision makers feel uninformed on management of invasive species is that the available knowledge is system and location specific (Walsh et al. 2015). So should scientists devote more time and resources to publish peer-reviewed papers on specific management measures? We argue that they should not. More specific knowledge on management options, even if published as peer-reviewed papers, will inevitably be even more system specific. Specific measures need to be tailored solutions to be successfully implemented.

While we focus in this article on scientists' contributions to the process, it will also be necessary to acknowledge in all three steps the different contributions of different decision makers (Barreteau et al. 2010). As our results show, priorities of the two groups of decision makers, i.e. recreational fisheries and conservation managers, differ to some extent (Fig. 2), and so will their contributions to the transdisciplinary process. Conservation managers, for example, can provide knowledge on the practical aspects of management implementation and enforcement; recreational fisheries, for example, can provide local knowledge on the invasion front through community-based monitoring (see Conrad and Hilchey 2011 for a review on citizen science and community-based monitoring). Again, we argue that a full disclosure of the underlying motivations for these priorities will improve the objective assessment of all contributions.

In any case, there is no substitute to a transdisciplinary process towards a joint research on and implementation of management. In the second step within this process, the fact that scientists cannot deliver the knowledge they themselves deemed as their essential contribution needs to be understood and communicated. The discrepancy between what the scientific community has in store and what is needed in the field needs to be openly discussed and solutions need to be found together.

Step 2: Communication

The second step is to openly communicate how priorities and knowledge match or mismatch by and among both groups (Fig. 3). Based on the concept of ''strong objectivity'', we expect that information on our own and others' priorities and knowledge facilitates reflexivity on each groups' contributions to the process. In this paper and in Hirsch et al. (2015), we aimed at disclosing the scientific basis of such priorities to facilitate reflexivity among us as scientists. This approach of an objective assessment and subsequent reflexivity can be the fundament of communication leading to rapid management action for two reasons. Firstly, neither player is left in the dark about where other players' contributions come from. Secondly, as sources of contributions are transparent, it is less likely that either player is waiting for knowledge or decisions the other player cannot and will not deliver. For example, our literature review indicates that impacts of a specific species can indeed be profound, but there is almost no scientific (i.e. peer-reviewed) knowledge on e.g. the relative effectiveness of different management measures.

Making scientific knowledge on invaders easily available to decision makers can improve the chances of a successful management (Drolet et al. 2014). There has been a great deal of attention devoted to what decision makers want from scientists and what scientists deliver. For example, decision makers want to receive more specific information on management measures (Walsh et al. 2015). In such a context, it is easy to simply aim for an improved unidirectional process of ''order and delivery'' such that decision makers request information and that scientists produce knowledge to eventually satisfy this request, without any feedback amongst these two groups involved. Our study suggests that, in the current situation, scientists do not hold the primary knowledge monopoly on management of invasive species. Scientists do not possess a body of knowledge within their community that can simply be transferred to decision makers. Also here, there is no substitute to a transdisciplinary process. Scientists and decision makers need to co-produce the knowledge that is most needed for invasive species management. It has to be avoided that decision makers wait for ‘‘secured scientific facts’’, while in the meantime the invader can establish and spread. Thus, scientists need to communicate that they do not have a tool box of tried-and-true management options from which the decision makers can pick. Instead, scientists and decision makers together have to appreciate their own and the other groups’ contributions to a joint research paradigm towards invasive species management (Fig. 3). Rather than playing the part of delivering knowledge, scientists can co-create knowledge together with decision makers if both groups follow a joint research paradigm. This process matches the transdisciplinary ideal of ‘‘science with’’ rather than ‘‘science for’’ society (Seidl et al. 2013).

Step 3: Joint research paradigm

The third and final step towards invasive species management will be to establish a joint research paradigm (Fig. 3). In the context of a transdisciplinary process, a research paradigm needs to be controlled by both decision makers and scientists (Seidl et al. 2013). The ultimate outcome of the joint research paradigm needs to be co-produced knowledge about which measures are efficient and effective. Also in other cases of environmental management, the timely involvement of decision makers allowed a co-production of knowledge about successful management measures (Burkhardt-Holm et al. 2005; Cowling et al. 2008; Reed 2008; Garc´ıa-Llorente et al. 2011). The scientific output in the form of efficient management measures would then also be implemented faster, more smoothly and with better compliance when both players will have planned it together. Scientists and decision makers have sought together to ‘‘maximize the trade-off between accuracy and utility’’ of a management from the beginning (Kornis et al. 2013).

These joint efforts are often published in technical reports addressing a specific situation such as the ‘‘Summary of the Rapid Response to Round Goby (Neogobius melanostomus) in Pefferlaw Brook’’ by Dimond et al. (2010). The existence of such local solutions has implications for the objective assessment of scientists’ contribution to invasive species management. Specific management recommendations are typically not published as peer-reviewed papers, suggesting that epistemic knowledge of scientists is not something that is created within the scientific community and can then be ‘‘transferred’’ to decision makers where it is awaiting application. In general, the power and applicability of local solutions jointly established with local decision makers is an important reason why transdisciplinary research can lead to successful management measures (Hirsch Hadorn et al. 2008). Yet, the acknowledgement of how well such local solutions work and the appreciation of research towards them have been found to be under-represented within the scientific community (Simberloff 2009).

We suggest that our butterfly model can facilitate research towards such local and specific management solutions for three reasons: firstly invasion biologists who objectively assess their own priorities and contributions will realise that the existing knowledge within their community might not match the priorities needed for a rapid management. Secondly, if scientist disclose the basis of their knowledge contributions and communicate this to decision makers, both groups are more likely to appreciate the need for a joint research paradigm (Seidl et al. 2013). Thirdly, if both groups have disclosed the sources or the knowledge basis of their own priorities and contributions, it will be easier to collaborate on an equal footing (Bayliss et al. 2013; Rosendahl et al. 2015).

CONCLUSIONS

Our study aimed to evoke an objective view of scientists' role within a transdisciplinary process. Importantly, we found that a ''strong objectivity'' that includes us as scientists in the assessment of priorities can reveal relevant and unexpected results. Our three steps towards the installation of a joint research paradigm demonstrate how an objective assessment of whether priorities and contributions match can be a solid basis for further communication. By realising what scientists prioritise and what they deliver, they can become an integral rather than auxiliary part of the transdisciplinary process. On a broader scale, our butterfly model gives clues how a mutual learning between science and society can be put into practice. In the context of invasive species, we conclude that more objectively assessing contributions to a co-production of knowledge, i.e. disclosing priorities and knowledge sources, can allow for a more efficient and timely installation of management measures.

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