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# How California is mobilizing boundary chains to integrate science, policy and management for changing ocean chemistry

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ABSTRACT

Boundary organizations play an important role in stabilizing interactions between science and nonscience. In this paper we focus on how boundary organizations not only serve a variety of actors across a complex science-policy landscape, but also actively shape that landscape over time through process, institution building, and partnership building. Some of these partnerships are with other boundary organizations, thus forming "boundary chains". We draw on our experiences in convening the West Coast Ocean Acidification and Hypoxia Science Panel, an interdisciplinary group of scientists working to inform regional, state and federal responses to complex ecological, social and economic issues with rapidly evolving scientific understanding. From within a landscape already populated with a diverse set of institutions and actors focused on this issue, we illustrate how the Panel itself functions simultaneously at different positions within multiple boundary chains, mobilizing a variety of boundary organization partners to deliver on its mandate. In describing these arrangements, we show how political context and a shifting balance among credibility, legitimacy, and salience as near-term priorities have shaped both the posture and focus of the panel at different stages in its evolution. This case study suggests that boundary chains are necessary in order to advance the integration of science and decision making related to a complex emerging issue, especially at the scale of the North American West Coast. We also examine the nature of links among boundary organizations, and the kinds of benefits they confer upon individual actors, and upon the network as a whole. In some cases the benefit is through increased efficiency or reduced individual transaction costs. In others, the existence of linked chains may increase the power and value of individual interactions. In considering the issues of efficiency and transaction costs, we argue that it is important to remember that boundary organizations and boundary chains tend to increase the overall number transactions in the system. Indeed, this is part of their value in linking science and decision making: they multiply and strengthen relationships in a space where interactions were previously both few and ineffective.


## Introduction

Linking science and decision making is hard, and requires specific capacity and resources. Research agendas and the needs of decision makers are often not well matched and individuals and organizations on either side of this divide lack incentives

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to collaborate (McNie, 2007; Sarewitz and Pielke, 2007). When they do take place, such collaborations encounter challenges such as conflicting goals, incompatible problem frames, and unfamiliar processes and vocabularies (Collins and Evans, 2002; Doremus, 2008; Jasanoff, 1987). Such collaborations also risk damage to the individuals involved through the "scientization" of politics and "politicization" of science. Yet interactions between science and decision making are an inescapable part of life in a democratic society (Guston, 2000; Jasanoff, 1990).

Boundary organizations have been advanced as important in bringing about constructive and productive interactions between science and politics. Originally described and theorized by Guston (2001), boundary organizations stabilize interactions across the boundary between science and nonscience by translating between these social worlds, maintaining accountability to each, and allowing the production of "boundary objects" that are meaningful and useful to diverse participants with differing world-views and goals. Evolving discourse and theory about boundary organizations have focused on how to fulfill this role effectively. But while the challenge of stabilizing the boundary has been examined from multiple angles, considerably less attention has gone toward the structure, practices, and general sustainability of boundary organizations themselves (but see Bednarek et al., 2015).

*Boundary organizations both react to, and actively shape, their context*

Frameworks for thinking about effective boundary organizations are driven in many cases by external factors, which are seen to define the strategies for, or limitations of the work of boundary organizations for a given case. For example, Parker and Crona (2012) point out that a boundary organization must navigate "enduring tensions" between, for example, institutions, epistemologies, cultures, and organizational goals. And they note that the balance among these pressures may shift over time, forcing a boundary organization to adapt in order to survive. Clark et al. (2011) advance a framework for characterizing boundary work based on two contextual variables – the use of knowledge in decision making processes and the type and source of knowledge – thus explicitly recognizing the importance of context. Similarly, the boundary chains approach discussed in this special issue helps to characterize the ways in which boundary organizations adapt to a changing context.

But while understanding the strategies for, and outcomes of boundary organization practices in different contexts is useful, we must not fall into the trap of viewing boundary organizations as entirely reactive to a context. In our view as practitioners, boundary organizations are not necessarily bouncing off of static elements (e.g., institutions, disciplines, problem framings, policies) in the landscape like pinballs. Instead, they are actively shifting and shaping their context as they bring together new partners, frame problems in new ways, and even create new entities and new spaces for negotiation and collaboration. They are not just establishing and maintaining new connections *across* a traditionally recognized boundary, such as science and natural resource management; they are also organizing and reordering participants within those disparate communities.

This idea of proactively altering the landscape within and across disparate communities is implicit in frameworks examining boundary organizations (e.g., Cash et al., 2003; Clark et al., 2011; Guston, 2001; Miller, 2001; Parker and Crona, 2012), but deserves more direct attention as an important function of boundary organizations. This is consistent with the observation by Feldman et. al (2006, drawing on Actor Network Theory, e.g., Latour 2005) that new relationships in a network are not durable without continued work and input, but that the process of maintaining those relationships is the very thing that opens them to change. "As a result," they argue, "there is always potential for change in the network, and stability is an ongoing achievement" (p. 90).

*Boundary chains reorder networks both within and across boundaries*

From our perspective as practitioners in a boundary organization, we believe that the theory of boundary chains – the topic of this special issue – begins to address the proactive work required to maintain stable interactions across the boundary between science and decision making. A boundary chain approach enrolls multiple linked boundary organizations in working with stakeholder communities across the worlds of science and decision making. Acknowledging that the work of boundary organizations often requires very specialized knowledge, it is theorized that the use of boundary chains can expand the reach of a project or program, while reducing transaction costs (Lemos, 2015; Lemos et al., 2014).

The boundary chains framework adds an important dimension to the literature on boundary organizations because it begins to account for the ways in which boundary organizations can proactively shape their environments in order to build capacity and achieve their missions. As initially represented (Lemos et al., 2014), this framework suggests boundary chains as a "new approach" to the work of boundary organizations. However, our experience as practitioners at an established independent boundary organization – the California Ocean Science Trust – suggests that the strategy of linking with partners who can become active collaborators in the design and execution of boundary organization functions is the norm for any operation exceeding a given temporal or programmatic scale.

We believe that there are many examples of this practice available, allowing for further investigation of theories about efficiency, transaction costs, and other potential benefits. In this paper we present one such example—the West Coast Ocean Acidification and Hypoxia Science Panel. The case adds new dimensions to thinking about the formation of boundary chains and their use in proactively organizing resources to facilitate constructive ongoing interactions between science and decision making. The case adds important nuance to the expectation that boundary chains will reduce transaction costs, by

highlighting the value they create by multiplying and strengthening relationships in a space where interactions were previously both few and ineffective.

## Methods: Informing theory with a practitioner perspective

In the following sections we present an account of ongoing work to manage and advance the West Coast Ocean Acidification and Hypoxia Science Panel (the OAH Panel). The OAH Panel is sustained through ongoing work on the part of multiple boundary organizations, collaborating with partners from across state and federal government, and academia. It should also be stated that our own organization, the California Ocean Science Trust, has played a central role in much of this work. One of the authors, who did not have direct involvement with the OAH Panel, has been responsible for drawing out insights about the case study through structured internal discussion and background research. This contributes to a formative evaluation, useful for hypothesis building and further exploration, both specific to the OAH Panel case, and to the general theory of boundary chains, and to the practice of proactively shaping context.

We want to explicitly recognize some of the analytical limitations in our approach. The analysis and conclusions herein result from a reflexive account, developed internally without formal independent evaluation. Our qualitative description is necessarily biased, and does not benefit from a systematic documentation of perspectives from across the participants involved in the case, or from external investigators. Because this case study is not yet completed, and because of our limited perspective, we do not aim to judge the overall success of the OAH Panel in this paper. We are primarily interested in bringing to light, with concrete examples, important aspects of the practices of boundary organizations in a complex science policy landscape. Despite the limitations acknowledged above, we believe there is considerable value in strengthening the engagement between boundary organization practitioners and academic theorists, and contribute our insights in that spirit.

In our description of the Panel's genesis and evolution, we focus on three aspects of boundary work described above: (1) how a shifting context shapes the approach to boundary work with respect to credibility, legitimacy, and salience; (2) how boundary chains have been crucial in organizing and sustaining a network; and (3) how the Panel is not only stabilizing the links between science and decision makers, but also constructing and solidifying aspects of the network on either side of this divide, in order to make cross-boundary links more feasible, robust and durable.

## Case study: The West Coast Ocean Acidification and Hypoxia Science Panel

Primarily the purview of academic research over the last decade, ocean acidification has recently been thrust to the forefront of ocean conservation issues (e.g., Rudd, 2014). Driven in part by uptake of carbon dioxide from the atmosphere, ocean acidification refers to a reduction of ocean pH and associated changes in ocean chemistry. As levels of atmospheric $CO_2$ have increased so has the amount absorbed by the ocean, causing ocean waters to become more acidic and reducing the availability of carbonate ions – key components in the shells of calcifying species including oysters, clams, urchins as well as the skeletons of corals and calcareous plankton. In a series of related chemical changes, increasing occurrence of hypoxic events—localized, temporary reductions in oxygen—add considerable complexity to this issue (Doney et al., 2012; Melzner et al., 2012).

The potential impacts of changes in ocean chemistry on economically or culturally important species and ecosystems are uncertain. Along the west coast of North America patterns of acidification and hypoxia reflect a complex interplay among uptake of carbon from the atmosphere, upwelling of cold deep ocean waters that are already more acidic, and local pollution inputs. These patterns in space and time may be even further complicated as cycles of rainfall and upwelling also shift as a result of climate change, adding further uncertainty to future predictions (Doney et al., 2012; IPCC, 2014).

Nonetheless, recent dramatic hatchery shellfish population declines, particularly in Washington state, have focused political and management attention on this issue (WSBRP, 2012). Decision-makers, from local to regional to national scales, are grappling with the challenge of better understanding the implications of ocean acidification and hypoxia for ocean resources, building management processes that can accommodate new, and rapidly evolving, scientific understanding, and seeking practical management interventions that may be effective on local and regional scales.

In 2012, the California Ocean Protection Council, a cabinet-level body chaired by the Secretary of Natural Resources, formally charged the California Ocean Science Trust (OST) with convening an ocean acidification and Hypoxia Science Panel to synthesize current scientific understanding, contribute new interdisciplinary perspectives, and link this science to decision processes in California. With funding from the California Ocean Protection Council (OPC), OST would serve as secretariat for the panel, while also performing a translational role, identifying and pursuing opportunities to link the Panel's work with decision making.

The choice of OST to fulfill this role stems from the organization's unique link to California state government. Although OST is an independent nonprofit, it was created pursuant to state legislation to advance a constructive role for science in ocean resource management and conservation decision-making (CORSA, 2000). OST's role with respect to state decision-making ideally positions it to take on the task of convening and managing the OAH Panel. This arrangement, locating the secretariat function in an established boundary organization already working with the state on a variety of ocean issues, also sets the OAH Panel apart from other traditional science panel structures.

As the OAH Panel was getting under way in California, the government of Oregon formally signed on with a Memorandum of Agreement, and Washington and British Columbia contributed Panel membership. The West Coast Ocean Acidification and Hypoxia Science Panel, including 20 experts from across a range of academic disciplines, was empanelled for 2 years beginning in November 2013. Drawing on expertise throughout the West Coast, the Panel is working to serve decision-makers across multiple scales of management and governance (see Fig. 1).

The Panel is convened by, OST, which provides staff support for meetings and working groups, alongside activities such as the science needs assessment (more on this below), that translate and build relationships across traditional divides between the science and decision maker communities. Working alongside OST, the Institute of Natural Resources (INR) in Oregon is also supporting the Panel in developing products that will be usable in decision making across state, regional and federal bodies.

Adding to the growing political momentum across the West Coast, high-level regional policy bodies are expressing a need for collaborative, science-based solutions. The West Coast Governors' Alliance on Ocean Health has cited ocean acidification as a priority ocean and coastal health issue (WCGA, 2012) and the Pacific Coast Collaborative (including the Governors of California, Oregon and Washington, and the Premier of British Columbia) recently identified ocean acidification as a priority issue (Brown et al., 2013a), and directly cited the work of the OAH Panel in a letter to President Barack Obama and Prime Minister Stephen Harper as key to establishing greater regional partnerships (Brown et al., 2013b).

## Framing the problem, and shaping the context

The sequence of events by which the panel was initiated and has developed offers one perspective on the demands, tensions and opportunities in the boundary between science and policy, and highlights the dynamic nature of working in this space. Fig. 2 depicts the chronological development of the OAH Panel, drawing from a complex web of interactions to highlight key steps in its evolution. These steps and the boundary events and products within each are not a comprehensive account but are selected to highlight important dynamics, which we discuss further in Section Boundary chains and the OAH Panel.

Below we explain the development of the OAH Panel chronologically, following the steps in Fig. 2. We have laid out these steps in the process in order to illustrate the fact that moving forward required tending to different aspects of the complex community that surrounded these events, including funders, government at different levels, scientists, and other private interests.

One way to understand these dynamics is to focus on how OST and the Panel itself balanced credibility, legitimacy, and salience (following Cash et al., 2003) as issues of concern to various participants and constituents. At each step, these issues

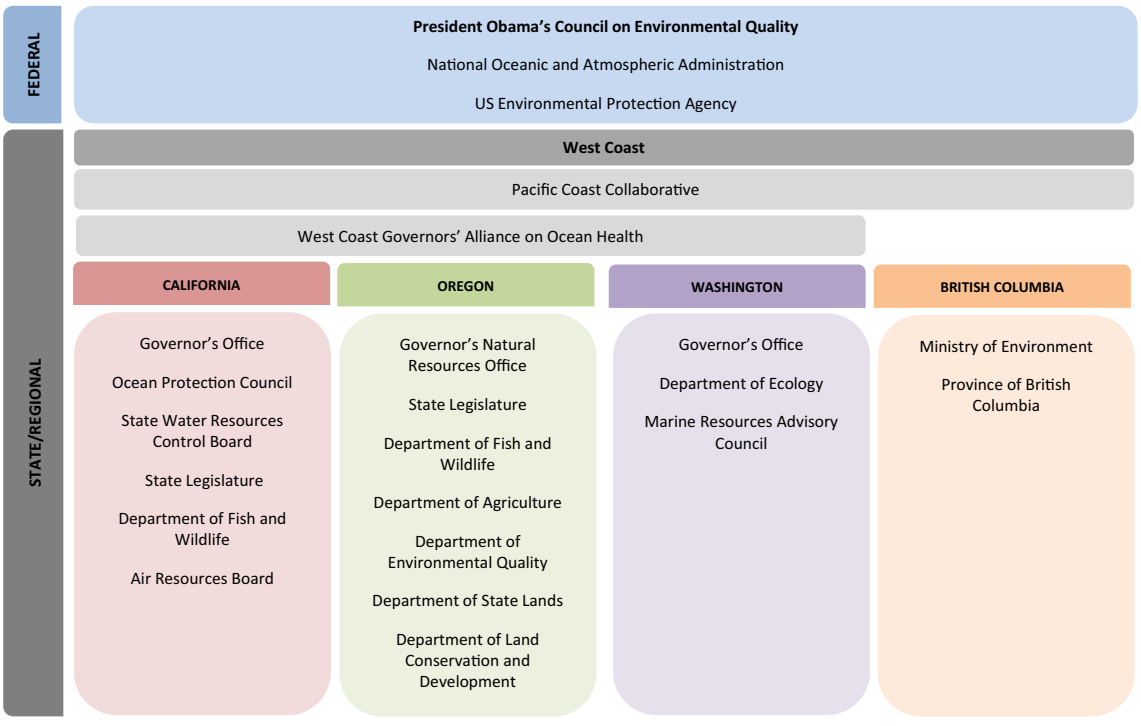


**Fig. 1.** Current management and policy audiences for the work of the West Coast Ocean Acidification and Hypoxia Science Panel.

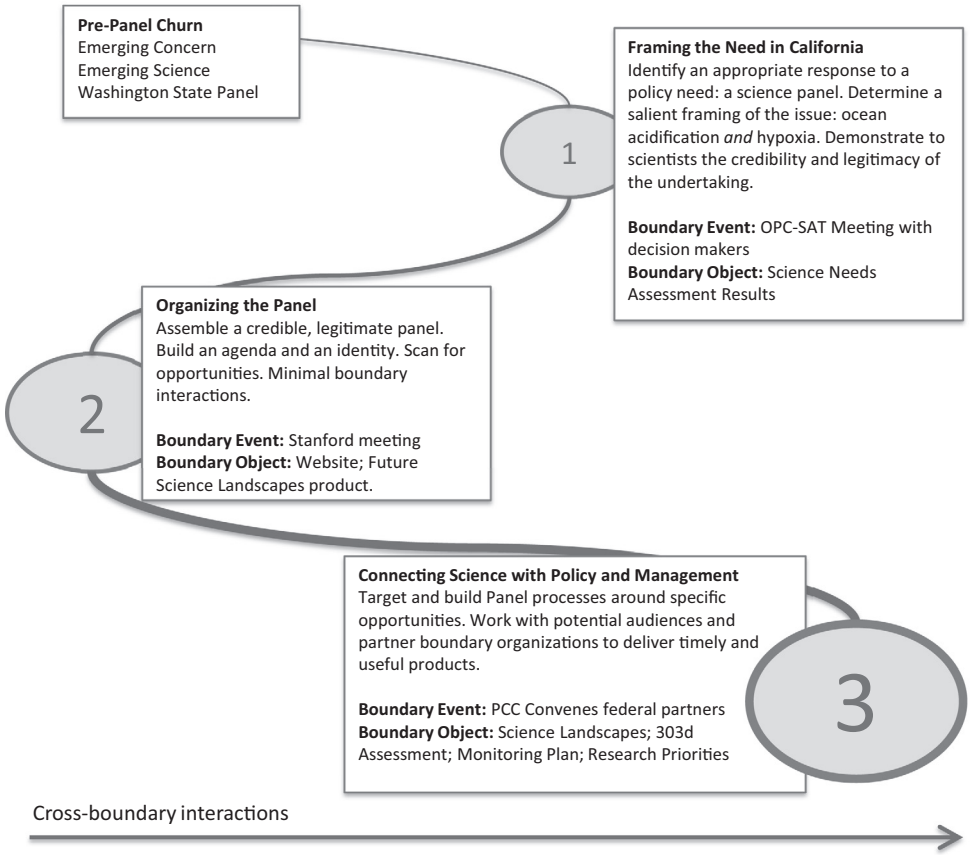


**Fig. 2.** Chronological account of three stages in the development of the West Coast Ocean Acidification and Hypoxia Science Panel. The arrow at the bottom indicates the intensity of interactions between science and decision maker communities.

were addressed through boundary events and boundary objects. These "interpretively flexible" objects (Star and Griesemer, 1989) have different kinds of meaning and value on different sides of the boundary, but maintain their identity across those social worlds. For each of these, we describe from our perspective how the boundary object or event was designed to engage different participants, acknowledging that no formal analysis has elicited participant viewpoints to corroborate this account.

### *Framing the need in California*

California has in place a governance structure that spans traditional divides among the water quality and natural resource management communities. The California Ocean Protection Council (OPC) by design seats the Secretaries of Natural Resources and Environmental Protection (alongside legislators and others) together, and serves as the policy body acting across state agencies on coastal and ocean issues. The OPC is a natural venue for tackling issues such as ocean acidification and hypoxia that span traditional water quality, fisheries and ecosystem management jurisdictional boundaries.

In 2012, California policy-makers faced a dilemma. As the potential economic impacts of ocean acidification on the shellfish industry in Washington and Oregon focused public attention on the issue, there was increasing pressure on the Ocean Protection Council and others in state government to understand the potential relevance and significance to California ocean resources more broadly, beyond impacts to growers. Yet, the predominant framing of ocean acidification as a global issue driven by global carbon emissions suggests a powerlessness at the state and local levels where these impacts are being experienced. Kelly et al. (2011) suggest potential local regulatory levers to manage contributors to ocean acidification, but tractability, benefits and costs remain unclear, and place undue responsibility on the water quality regulation and management agencies and departments. Thus, prioritizing this issue could arguably be seen to be drawing resources away from demonstrably tractable issues of more immediate and certain economic and ecological concern. It also raises questions about the ability of decision-makers at local and state scales to respond to new scientific information on an issue that spans traditional jurisdictional boundaries.

Public testimony before the OPC by the Executive Director of the Southern California Coastal Water Research Project (SCCWRP) offered an alternative framing of this issue for California. A growing scientific literature is illustrating the complex links between ocean acidification and hypoxia and also connecting local hypoxic events to local nutrient and water influxes

to coastal waters and estuaries (McClatchie et al., 2010; Melzner et al., 2012). Along the urban coast of southern California, water discharge regulators and agencies are under particular pressure to understand the relative importance of local, regional and global drivers of acidification *and* hypoxia, and to understand the responsibility of the water quality community to implement management actions.

OPC settled on this framing of ocean acidification as linked with hypoxia, and charged OST with convening a panel. OST then focused attention on securing buy-in to that framing among the science community. Not all scientists would be comfortable with combining the issues of ocean acidification and hypoxia, nor would it be immediately obvious to them that participation in an effort such as this would be worthwhile (as it could seemingly further divert attention from ecological impacts or the global driver of greenhouse gas emissions). This challenge was addressed through two process steps.

The first step was to produce a boundary object: the combined results of two science needs assessments conducted in parallel by OST and INR in California and Oregon, respectively. To conduct the science needs assessment, OST and INR interviewed a range of managers and decision makers at the federal and state level to better understand how different actors are viewing the issues of ocean acidification and hypoxia, the processes in place to deal with them, and the potential role that existing and new science can play in those management frameworks (OST, 2014a, 2014b, 2014c).

The second process step—convening a boundary event—was the November, 2012 meeting of the Ocean Protection Council Science Advisory Team (OPC-SAT) (Fig. 2, Step 1). Empowered by the legislation that established the Council (COPA, 2014), which calls for science-informed decision-making, the OPC-SAT provides a high-level mechanism for discussion and collaboration between California policy-makers and managers and the scientific community. A meeting of the OPC-SAT, which is convened by a boundary organization—OST—provided an appropriate venue to scope, shape and launch an ocean acidification and hypoxia science panel that would have the provenance and authority required to successfully achieve its mandate.

Results of the science needs assessments were presented at the OPC-SAT meeting, which was also attended by several of the managers who had participated in the interviews. Our goal in convening this meeting was to provide an opportunity for scientists to better understand the context and relevance of the ocean acidification and hypoxia framing, and for further negotiation of that framing as advisory team members raised questions based in their own disciplinary perspectives. The meeting also provided an opportunity for members of the Washington State panel (WSBRP, 2012) to discuss their efforts and share the next steps they had identified as part of that effort, some of which were now underway.

Discussions during this meeting engaged OPC-SAT members—some of whom would later become Panel members—in a policy and management dialogue, deepening their appreciation of the challenges faced by decision-makers in using scientific information that is rapidly changing and still uncertain. These discussions were bolstered by the broader-reaching, and more formal results of the science needs assessment, which could serve as a touchstone. Decision makers could see a formal embodiment of the priorities they were expressing, while scientists could see that there was a formal agenda to which they would need to be responsive in order to participate effectively. These discussions, centered on the results of the science needs assessments, were instrumental in demonstrating to the OPC-SAT a legitimate interest on the part of managers and policy-makers, and the existence of decision-processes in place to take up and use products generated by an OAH science panel.

Shortly following the OPC-SAT meeting, the governments of Oregon, Washington and British Columbia, through discussions with Ocean Protection Council leadership, formalized their participation in the Panel, named then as the West Coast Ocean Acidification and Hypoxia Science Panel. Expanding the geographic scope across the West Coast then attracted the attention of federal lawmakers who began to seek engagement with the Panel as a mechanism to advance President Obama's Executive Order 13547, which explicitly calls for coordinated regional action on ocean issues (NOP, 2010).

The OPC-SAT meeting generated high-level scientific buy-in to the idea of a science panel, its disciplinary scope and framing of the issue, and a list of broad questions that address decision-maker needs. While this was an important outcome, a panel was yet to be established, let alone a specific list of deliverables and targeted outcomes. In other words, while communities on either side of the boundary were prepared to participate, this buy-in was highly contingent, and would require ongoing effort to sustain.

### *Organizing the OAH Panel*

Following the OPC-SAT meeting, which established and strengthened links across the science-policy divide, our focus turned to assembling and convening the OAH Panel. In the boundary chain construct, the panel itself is akin to a boundary organization with links to the convening organization, OST, and others that fulfill particular roles (discussed further in Section Boundary chains and the OAH Panel). Establishing the panel therefore involved a range of considerations extending beyond the technical merit of potential panelists, such as its ability to deliver relevant, useful, and legitimate products to a range of partners and broader audiences.

Assembling the OAH Panel involved selection and invitation of scientists based on political, geographical, institutional, and disciplinary considerations. There are many branches of research relevant to ocean acidification and hypoxia, from chemistry and physical oceanography to physiology, ecology and resource management. Identifying a limited number of panelists meant encompassing these domains while also accommodating representation across the states and British Columbia. OST worked initially with the OPC, and the OPC-SAT to identify potential panelists that would address California's needs. Final selections were made by the OPC-SAT executive committee and presented to OPC. As other

governments formalized their participation, OPC staff worked with counterparts in Oregon, Washington and British Columbia who each selected a limited set of additional panelists.

Within the resulting panel, a chair was appointed from the OPC-SAT, supported by an executive committee comprised of working group leads and representing each state (see below), with OST serving as the secretariat. OST and counterpart organizations in other states/provinces would work directly with the panel to link outputs with state decision makers (more on this in Section An emerging keychain arrangement).

A full panel workshop—the Stanford Meeting—launched the primary activities and work of the Panel (Fig. 2, Step 2). In some respects this meeting mirrored the previous OPC-SAT meeting: bringing state and federal decision-makers together with the scientific community, now represented by the panelists. As with the OPC-SAT meeting, this was an important opportunity for panelists to understand the commitment of decision-makers to act on the issues of ocean acidification and hypoxia and to begin to understand the importance of the multi-disciplinary perspectives provided by fellow panelists. Applying technical understanding of the issue, and in response to expressed science needs, panelists formed working groups that collectively would address the questions posed by managers. The Stanford Meeting helped to establish a separate identity for the OAH Panel. Concurrently, OST developed a website, logo and visual identity for the Panel, thus helping to solidify and externally represent its growing institutional capital (http://westcoastoah.org).

The Panel and its working groups grappled initially with the rapidly evolving understanding of ocean acidification and hypoxia as well as disciplinary differences in the treatment of, and comfort with, scientific topics such as complexity and uncertainty. To learn how to work together within the framing of ocean acidification and hypoxia, the Panel decided collectively in this initial stage to produce a set of scientific manuscripts aimed at academic journals. These include a synthetic state of the science review of known impacts of acidification, oxygen and temperature on physiological responses of individual organisms, a perspective on paths to holistically address changing ocean chemistry through management that builds ecosystem resilience despite uncertainties, and a new conceptual approach to integrate onshore and offshore oceanography and chemical processes.

It is possible to view this period in the tenure of the OAH Panel as an investment in scientific endeavor that did relatively little to span the boundary. After all, the Panel was engaging in a highly technical discussion aimed at producing journal articles that would get very little attention outside of academia. However, this investment of time was specifically intended to establish credibility and mutual understanding among panelists. In other words, these activities built trust across boundaries that separate scientific disciplines, to develop a collective voice that could be more effective in dialog with decision makers. While the OAH Panel focused its work on the science side of the boundary, OST, working alongside state partners at OPC, and INR, cultivated relationships and sought venues for future panel products, including tailored management-relevant documents, meetings and briefings where the work of the Panel could present the most salient scientific thinking.

Concurrently (Fig. 2, Step 2), OST was developing a product that grew out of the iterative discussions within the working groups. "Envisioning Future Science Landscapes" draws on semi-structured interviews with panelists and other experts, who were asked to express a future vision for ocean acidification and hypoxia science: how knowledge may evolve, how it will be used and how the scientific community can collaborate in new ways. The product describes how, through the work of academic research consortia together with agency-supported monitoring programs and the OAH Panel itself, the West Coast is well positioned to support federal action on the broad issue of a changing ocean chemistry (including ocean acidification and hypoxia). This boundary object, on the one hand, asks participating scientists to engage with ideas about how the science system can evolve to be more responsive to decision makers, and to see themselves in that vision. In that sense it is an institution building exercise for the panelists. On the other hand, it expresses a vision that funders and decision makers can embrace and, hopefully, take up in higher level policy discussions about these issues.

However this product hit a stumbling block prior to release. As panelists considered the content, some felt that it was too soon to release this vision – ahead of the academic publications from the panel working groups that would solidify the state of scientific understanding on these issues. Panelists expressed a legitimate concern that the product could undermine the scientific credibility of the panel working group products. By comparison, in the policy and management sphere, drafts of the document were seen—for example by OPC leadership, Council members and the Pacific Coast Collaborative—as the foundational steps needed to ready the landscape for release and use of subsequent panel products. This tension is not surprising but rather highlights the importance of the time—and resources—devoted to each side of the boundary during this period, without significant interactions between the two.

*Connecting science with policy and management*

The mid-point of the Panel's tenure was a natural pivot in the focus of its activities. With the science framing established, and foundation built through work on journal articles, the focus turned toward connecting science effectively with decision-making clients and audiences. Both OST and INR began to share with decision-makers (1) updates on Panel progress in developing foundational science products, including key messages from those efforts; (2) a more detailed vision of next steps for the Panel in the coming year, and; (3) detailed conversations about the ways in which the Panel could generate useful information for their work.

Meetings, briefings and webinars with state decision makers along the coast, including briefing the Pacific Coast Collaborative (PCC) and others at the regional and federal level, began, and continue to, serve as a way to target information needs with appropriate panel outputs in the right form and at the right time. OST and INR are developing these products in

full partnership with the Panel, which reviews them for scientific rigor and credibility. Through these activities the Panel is now turning attention toward immediate opportunities to inform policy and management in collaboration with OST and INR.

For example, state and federal regulators seek to understand how ocean acidification (exclusive of hypoxia) would fit into existing regulatory frameworks such as 303(d) listing of impaired water bodies (CWA, 1972). A Panel report addressing this has the potential for immediate consideration and application. Further OAH Panel products that were scoped through engagement with decision-makers are described in Box 1. Each builds upon the scientific foundation of the working group products, is directly responsive to a request, and is aimed at a specific process related to policy or management.

Box 1 Examples of products from the OAH Panel that link science with management and policy needs and decisions.

**Scientific Approaches to Making a 303(d) Assessment for Near Coastal Acidification & Biological Standards Update** – When monitoring data indicate water quality standards are not being met, management agencies have the option under Section 303d of the Clean Water Act (CWA, 1972) to list the water body as impaired and shift management emphasis from regulation of individual point source effluents to a more holistic evaluation of cumulative loading to the water body through the total maximum daily load (TMDL) allocation process. The Panel will analyze how the Clean Water Act can be deployed on this issues of ocean acidification and hypoxia given available data. These companion products will empower federal and state water quality managers to thoroughly evaluate if water quality standards are being achieved with existing data, identify key data gaps in monitoring programs, and explore the development of biological standards.

**Ocean Acidification & Hypoxia Research Priorities** – Identified via the Panel's scientific deliberations, this product will separate the 'nice to know' from the 'need to know' by identifying knowledge gaps that inhibit thoughtful action on ocean acidification and hypoxia. This product will enable federal and state research programs to make more strategic funding decisions in the coming years.

**Ocean Acidification & Hypoxia Monitoring Framework** – The California Ocean Protection Council has requested, and the Pacific Coast Collaborative has expressed interest in, a brief summary that recommends a strategic approach for a management-relevant, cost–effective monitoring program across the West Coast. Identifying assets, goals and knowledge gaps, the Panel is positioned to provide the conceptual framework for a monitoring program that could serve future funding decisions.

## Boundary chains and the OAH Panel

The story of the OAH Panel, described in the previous section, illustrates the ongoing work required to maintain links across the different social worlds involved, as well as to strengthen and in some cases reorder activities on various sides of that boundary. Here we explore this further by considering this work within the construct and model of boundary chains that connect science to policy and management.

A variety of organizations working on ocean acidification and hypoxia have played a boundary-spanning role in relation to the work of the OAH Panel over the past year. We define this role by activities that promote interactions between, and develop trust and accountability to communities important to the work of the OAH Panel. The Panel itself, as it has developed an identity, has linked between academic communities and other boundary organizations, particularly OST and INR.

Ocean Science Trust (OST) served the role of establishing the Panel in close partnership with the California Ocean Protection Council. OST facilitates links between the Panel and California policy and management communities. But as the convener of the Panel, it is also instrumental in establishing, tracking, and coordinating other boundary chain links in the network. For example, Oregon's Institute for Natural Resources (INR) coordinated its science needs assessment with guidance from OST, and is in regular contact with OST about the work of the broader panel as it focuses on Oregon-specific issues, which in turn informs OST's and California's efforts with the OAH Panel, that will ultimately serve the entire coast. OST's proactive work across science and decision making communities shaped panel products that could connect science with decisions (Box 1).

The Pacific Coast Collaborative (PCC), formed through an agreement between the leaders of Alaska, British Columbia, Washington, Oregon, and California, provides a formal basis for international cooperative action. For the purposes of the OAH Panel, PCC serves as a link among the three US states and the province of British Columbia. It allows for a single voice that can speak more powerfully to federal lawmakers, regulators and policy audiences about Panel activities and products than would any single state or province.

The Southern California Coastal Watershed Research Project (SCCWRP), whose director and key staff serve as panelists, is an important participant because of its intimate involvement in water quality science and policy at both state and federal levels. In addition to contributing science expertise through direct involvement in the Panel, the Executive Director of SCCWRP has worked with OST to broker relationships with federal and state water quality decision makers. Moreover, this perspective–shared via public testimony–launched the ocean acidification and hypoxia framing of these issues.

*Linked chains*

For each of the boundary objects described in the previous sections, there is a particular arrangement of organizations that enables interactions between the OAH Panel and key constituents. Fig. 3 illustrates three examples of these linked chain arrangements. The Future Science Landscapes product (Fig. 3a) serves a variety of purposes, as described in the previous section. The same linked chain arrangement, through parallel dialogue, connects a scientific approach to integrated ocean monitoring with federal decision-makers. Although the monitoring framework is currently under development, the approach is intended to facilitate new links between the National Oceanic and Atmospheric Agency (NOAA) charged with building and supporting natural resource monitoring programs and Environmental Protection Agency, charged with building and supporting water quality monitoring programs (Fig. 3c). By contrast, the product considering the potential role of ocean acidification in the 303d listing process (Fig. 3b) draws on the particular expertise of SCCWRP, which links directly with relevant research based at UCLA, to provide a tactical and focused scientific assessment relevant to a specific legislative mandate, the Clean Water Act.

*An emerging keychain arrangement*

As discussed above, the OAH Panel was initiated through the authority of the California Ocean Protection Council, and originally conceived as an effort to inform California decision makers about the linked challenges of ocean acidification and hypoxia. While it quickly became clear that there was potential to expand participation across the West Coast, establishing mechanisms that involve these communities effectively has been an evolving process.

In addition to conducting a science needs assessment in Oregon, the INR is directly staffing the five members of the panel from Oregon, and planning to communicate panel products to its constituents throughout the state. The Washington Acidification Center, which was formed as a result of that state's earlier work on synthesis and assessment of ocean acidification science (WSBRP, 2012), is also forming a link to the Marine Resources Advisory Council. That body is made up of government and non-government stakeholders concerned with ocean acidification. Finally, British Columbia's panel representatives, through the Pacific Institute for Climate Solutions, are briefing Canada's federal decision makers.

These organizations are performing boundary spanning functions on behalf of other states involved, resulting in a keychain arrangement (Fig. 4). As described by Lemos et al. (2014), a keychain arrangement allows one boundary organization with limited resources to expand the diversity of partners involved by enrolling additional boundary organizations that can link with specific audiences (in this case state/province-level decision makers).

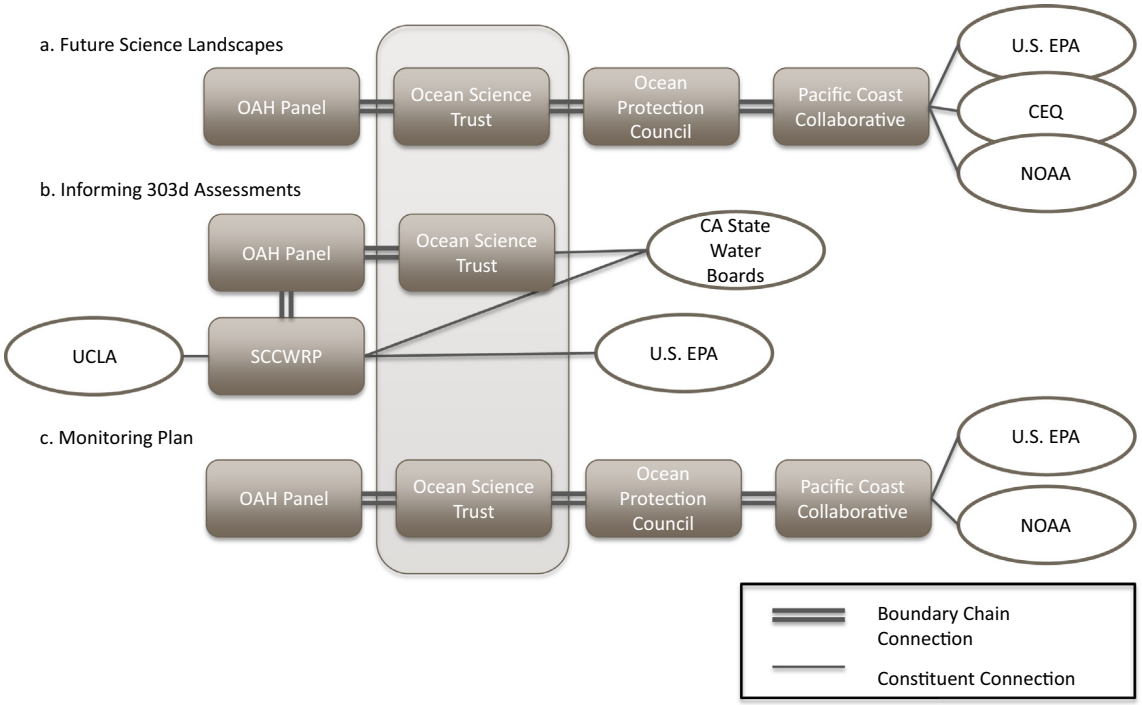


**Fig. 3.** Illustrations of linked chain arrangements, each associated with a specific product planned for release by the West Coast Ocean Acidification and Hypoxia Science Panel: (a) Future Science Landscapes Vision; (b) Scientific Approaches to Making a 303d Assessment; and (c) Ocean Acidification and Hypoxia Monitoring Plan. Shaded vertical bar highlights the presence of OST as a common thread across chains, though its role varies from one to the next.

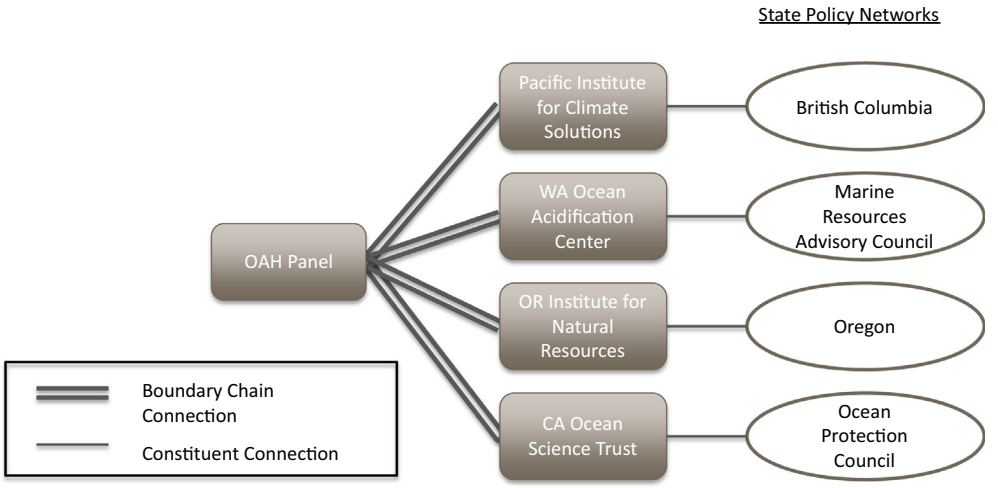


**Fig. 4.** A keychain arrangement allows locally based boundary organizations to translate between the West Coast Ocean Acidification and Hypoxia Science Panel and state level policy and management communities.

*Evidence of a networked boundary chain*

Lemos et al. (2014) define a networked boundary chain as an arrangement in which organizations in multiple linked chains benefit one another through increased opportunity for interactions. For example, OST's approach to science needs assessment was taken up and adapted by INR. The early experiences of the Washington Ocean Acidification Center are informing the ways in which other links in the chain engage with decision makers. In other words, individual transactions may be more efficient because of shared resources and knowledge transfer.

Another way to think about this is a network in which the existence of other links increases the power or value of one specific interaction within spheres of science, policy, and management. One small example of this is recent testimony before the US Congress by one of the OAH panelists. In this case the scientist was not formally representing the OAH Panel, and the link between him and the policy makers was brokered by COMPASS, an organization without formal involvement in the Panel. Nevertheless, the scientist's membership in an interdisciplinary panel representing two nations conferred increased legitimacy to the testimony. Further, reflections from this briefing informed the work of the Panel.

There is also good potential for strengthened networks within and across communities on the West Coast. Deepened scientific understanding of ocean acidification and hypoxia developed through the Panel products has revealed pitfalls in policy and management responses that address these issues in isolation. Instead, a holistic approach to a changing ocean chemistry broadens the range of natural resource and water quality management frameworks that are needed to adapt to a changed future. The Panel is now working to improve communication and coordination among a broad swath of research institutions and funders relevant to the impacts of changing ocean chemistry. As mentioned above, the boundary organizations involved with policy and management at the state level (Fig. 4) may also benefit one another through exchange of best practices and coordination on West Coast-wide policy issues. In all of these examples it will be difficult to prove conclusively the impact of the OAH Panel on scientific advances, policy action and new management approaches. However, the sustained effort to coordinate among these diverse actors and build capacity through that effort, is increasing the density of interactions, at least for the time-being.

## Concluding discussion

*The OAH Panel and the boundary chain model*

This case study is in many ways consistent with the boundary chain model described by Lemos et al. (2014) and exemplified by other cases in this special issue. While the Ocean Science Trust's work on the OAH Panel was not specifically designed with the boundary chains framework in mind, it contains multiple examples in which boundary organizations rely on links with one another in order to accomplish particular tasks, or improve outcomes. In some cases this is aimed at expanding the scope and reach of the effort. For example, linking with INR expanded the scope of the science needs assessment, and built relationships between the Panel and Oregon policy and management communities. In other instances, boundary chain links serve to narrow in and build relationships necessary to develop a specific product for a specific audience. While there were already relationships with USEPA and the Water Boards through the Ocean Science Trust, the link with SCCWRP was crucial in moving forward work to inform the utility of the 303d assessment framework for OA.

This latter example relates to the cautionary tale about the risks of "being all things to all people" (Parker and Crona, 2012). To avoid this fate, links in boundary chains should be pursued judiciously, and not always with the goal of expanding participation and scope. Indeed this problem of choice in developing new links in boundary chains may be usefully informed by existing boundary organization theory (e.g., Cash et al., 2003; Clark et al., 2011) focused on the dynamics of decision making context and the types of knowledge involved.

Key to the boundary chains theory is the idea that they reduce transaction costs, thereby increasing efficiency. While recognizing that transaction costs are an important issue to examine, we offer a somewhat differing perspective. The boundary chain model is specifically aimed at expanding the reach and improving the effectiveness of a single boundary organization, and this was certainly the case with the OAH Panel. But to argue that this improves efficiency is to posit that achieving the same reach and effectiveness as a single organization would be much more costly and cumbersome than would a boundary chain approach. But the counterfactual in this case is simply not realistic. In other words, it's not that going alone would be more cumbersome, but that going alone is not a viable approach to meeting the goals. In the present case study the outcomes achieved would simply not have been possible without the boundary chain links, because no single organization has the credibility or legitimacy needed to engage the diversity of constituents involved.

It is also important to avoid conflating transactions costs (referring to the cost of a given transaction), with the overall investment in transactions. A boundary chain approach may reduce the costs of individual transactions by devolving responsibility to organizations that are better equipped to work with specific groups. However, in this scenario the overall number and density of transactions is likely to increase, and thus the total cost may not be lowered through this approach.

Indeed, many of the boundary chain links formed around the OAH Panel have *multiplied* transactions. Moving from a California focus to a West Coast focus has greatly increased the number of relationships that need attention on a regular basis. By framing the Panel around both ocean acidification *and* hypoxia, the issue became more tractable and more broadly meaningful in the eyes of state decision makers. But this also meant involving a broader cross-section of the scientific community, due to the added complexity of these two interacting phenomena. This meant not only more scientists involved, but also a greater need for relationship building among scientists not familiar with each other's work (the primary focus of phase 2, as represented in Fig. 2). These new connections all take time and effort, but that is precisely the point.

In short, we argue that individual transaction costs may be reduced by boundary chains, but that overall transactions may increase dramatically. Boundary organizations are typically motivated by a lack of constructive interactions among communities. They by their very nature multiply transactions through translation, mediation, and co-production. The point is not that these functions would be inefficient and costly in the absence of a proactive boundary organization, but that they simply would not occur.

The OAH Panel is working at the state and federal levels, and involves formal participation by four states across two countries. It may have been possible to build a single new boundary organization that can deal with this diversity and complexity on its own, but such institution building presents its own challenges. Based as it is in an existing boundary organization with a variety of other programs and a California focus, the Panel's boundary chain approach was, we believe, the only viable approach to orchestrating this effort to link the evolving science of ocean acidification and hypoxia with policy and management communities.

It is likely that beyond a certain scale, the boundary chain approach becomes a necessity, rather than a choice. Though it is hard to determine the precise nature and location of this threshold, important factors likely include the jurisdictions involved, disciplinary breadth of the science involved, and breadth of policy, regulatory or management relevance of the undertaking.

### *Boundary organizing within and across communities*

The West Coast Ocean Acidification and Hypoxia Science Panel offers an instructive example of the ways in which boundary organizations do much more than facilitate constructive interactions across disparate social worlds. They proactively organize, re-order, and re-frame activities within those worlds. The Panel's work is helping to focus attention on the multiple drivers, including acidification and hypoxia, of a changing ocean chemistry, with direct relevance to local coastal waters. Scientists are collaborating in new configurations, and thinking about how the science system (as opposed to individual scientists) can respond to decision maker needs. This is an example of the proactive boundary work referred to in our introduction: re-shaping the context to promote better interactions between science and decision-making.

The ongoing stability of these new arrangements is an open question. The fact that they were possible at all within the timeframe of the Panel's first year speaks in part to the ripeness of the issue of ocean acidification as measured by public testimony and media coverage, the openness of key actors such as the OPC to collaborative science-informed policy making, and the availability of resources to pursue the many different activities now associated with the Panel. Perhaps the most appropriate measure of success will be the sustainability of new relationships and approaches to a changing ocean chemistry in the absence of such focused effort and investment, and beyond the anticipated tenure of the Panel itself. As discussed above, maintaining such a network requires input of energy, which in turns opens up the system to change (Feldman et al., 2006). In the face of increasing resource management challenges resulting from a changing climate, continued attention to discourse about ocean chemistry will allow further learning, to hone and realize the value of novel boundary organizations as effective mechanisms to connect science with policy and management.

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