Marine Policy (xxxx) xxxx–xxxx

Contents lists available at ScienceDirect

Marine Policy

journal homepage: www.elsevier.com/locate/marpol

Five rules for pragmatic blue growth

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ARTICLE INFO

Keywords:
Blue growth
Ecosystem-based fishery management
Blue economy

ABSTRACT

The concept of blue growth is the newest of many recent calls for more holistic management of complex marine social-ecological systems. The complexity of ocean systems, combined with limitations on data and capacity, demands an approach to management that is pragmatic—meaning goal- and solution-oriented, realistic, and practical. This article proposes and discusses five rules of thumb upon which to build such an approach. 1) Define objectives, quantify tradeoffs, and strive for efficiency. Understanding stakeholders' objectives, and the nature of tradeoffs between them, keeps management goal-oriented, aware of its full range of options, and maximizes the likelihood of finding win-win solutions. 2) The data you have can do more than you think. Cross-system similarity, within-system complexity, and general first principles all add informational value to data collected both within and outside the system being managed. 3) Engage stakeholders, but do it right. Co-management and citizen science can be important tools in the science and management toolbox, especially in data- and capacity-limited regions. 4) Measure your impact and learn as you go. This can increase short-term start-up costs but can prevent larger wastes of resources in the long-term. 5) Design institutions, not behaviors. Management does not directly control fishing efforts, pollution rates or other behaviors, but instead controls institutions under which stakeholders make choices. Each of these rules of thumb is inspired by real-world successes and case studies. Concrete examples are used to illustrate key concepts, with the aim of providing a digestible set of guidelines that any manager can follow.

1. Introduction

Blue growth [1] is an ambitious framework for ocean management. It recognizes that diverse ocean uses—such as fisheries, shipping, and tourism—and marine ecosystem services—such as food provisioning, coastal protection, and carbon storage—are interconnected, and additional value can be gained from managing these uses and services jointly rather than managing them separately.

The advantages of holistic ocean management motivating the call for blue growth are analogous to the hypothesized advantages of ecosystem-based fishery management (EBFM) [2,3]. These advantages arise from two main sources. First, when different parts of a system interact (e.g., shipping impacts the fishing industry), managing each component separately tends to produce sub-optimal outcomes at the system level, even if all components are managed for the same objectives. For example, managing several interacting fish stocks individually to maximum sustainable yield (MSY) will almost never result in ecosystem-wide MSY [4,5]. Second, models and projections of individual components of the system are often biased by failing to account for interactions with other components. For example, single-species stock assessments can be biased by failing to account for ecosystem-level interactions [6,7].

Similar analogies between blue growth and other forms of holistic management can be used to anticipate some of the implementation challenges and pitfalls that will need to be overcome. The experience of EBFM, for example, suggests these challenges can be significant [8] (but see also [3]). The challenges are largely rooted in complexity and scale: A more holistic focus necessitates understanding a larger and more complex system, which can increase data requirements and modeling difficulty; increasing the number of stakeholders involved can also make coordination and consensus more elusive.

These challenges are surmountable in that they need not prevent holistic management frameworks from improving upon status quo. However, meeting these challenges demands a pragmatic approach to

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http://dx.doi.org/10.1016/j.marpol.2016.12.005
Received 7 December 2016; Received in revised form 11 December 2016; Accepted 11 December 2016

Please cite this article as: Burgess, M.G., Marine Policy (2016), http://dx.doi.org/10.1016/j.marpol.2016.12.005

both science and management.

The pragmatic approach to managing blue growth envisioned here is organized around clear objectives, a realistic focus on what is or can be achievable (and what it takes to get there) and what is known or knowable (and what it takes to learn it), and outside-the-box thinking to make the most of the data and capacity available. A pragmatic approach explicitly recognizes the costs of scientific and management infrastructure and seeks to maximize the net benefits, while explicitly accounting for the value of information. It also recognizes the existence of unknowables and therefore places some management emphasis on resilience—an essential design feature in an uncertain world [9]. Finally, as blue growth is a sustainable development initiative [1], this article takes as precept that blue growth has long-term objectives.

This article proposes and discusses five rules of thumb to help guide a pragmatic approach to blue growth. In each case, concrete illustrative examples are provided, often but not exclusively from fisheries—our primary area of expertise. These rules are not comprehensive, but hopefully offer a valuable launch point for more expansive discussion and detailed analysis.

2. Five rules

2.1. Define objectives, quantify tradeoffs, and strive for efficiency

Managing complex systems often involves making tradeoffs between conflicting stakeholder objectives; this naturally leads to conflict. In the oceans, fisheries, tourism, and shipping all compete for space and all impact the ecosystem to some degree (e.g., [10]). Fisheries that target different species can come into conflict with each other when one species is caught as bycatch in the other's fishery (e.g., [11]), or when the species interact ecologically (e.g., [12]). Within or across sectors, profit objectives can conflict with equity, subsistence, or recreation (e.g., see [13] for a fisheries example).

When managing for competing stakeholder objectives, it is important to have a clear understanding of what these objectives are and how they interact. This enables quantification and communication of tradeoffs between objectives, so that managers and stakeholders: (a) understand the full range of management options, and (b) avoid false tradeoffs and conflict when win-win opportunities are possible [14].

Efficiency is a good first target when managing for multiple objectives that are difficult to objectively compare (e.g., conservation and profits). If all objectives can be perfectly measured and aggregated into an agreed-upon (or objectively 'true') social welfare function, then efficiency simply refers to picking the management intervention that maximizes aggregate social welfare. But in the typical case where the social welfare function is contentious or poorly understood, it can be useful to examine the tradeoff space across different objectives. In such a tradeoff framework, efficiency means that an outcome has been achieved from which it is not possible to improve in one objective without regressing in at least one other. For example, if the objectives were profits and conservation, efficiency would mean that profits could not be increased without damaging conservation and vice-versa. Starting from a place of inefficiency, win-wins are available (e.g., improvements in both profits and conservation). Pursuing win-wins does not require subjectively weighting objectives against each other because managers can have it both ways. In contrast, when starting from an efficient state, management faces unavoidable tradeoffs. Thus, the 'true' nature of a tradeoff between two objectives is measured by an 'efficiency frontier'—the set of all possible efficient outcomes (illustrated in Fig. 1A).

Studies have evaluated the efficiency of resource management in a wide variety of contexts. Often, they have found the current management or state to be inefficient (e.g., Polasky et al. [15] in the context of land use; Mueller et al. [16] in the context of fertilizer use; Jacobsen et al. [5] in the context of fishing within an ecosystem). No study can evaluate every possible objective, so some management systems may seem inefficient in lower dimensions when they are actually efficient once other important objectives are accounted for (illustrated in Fig. 1B; e.g., see [17,18] for discussion in the context of incorporating often unaccounted-for equity objectives). However, there are also undoubtedly many untapped opportunities for win-wins—especially in systems with little coordination among interacting sectors or stakeholders. These inefficiencies compound as the scale of analysis increases; globally, many are striking. For example, Mueller et al. [16] estimated that more efficient global agriculture could nearly halve nitrogen fertilizer use without decreasing food production, or conversely, increase production by ~30% without increasing fertilizer use. Costello et al. [19] estimated that global fisheries reform could simultaneously increase yields, profits and biomass by respectively ~15%, ~100%, and~50%. The International Energy Agency [20] estimates that 6 trillion USD in net savings are available globally in the next two decades from energy efficiency improvements.

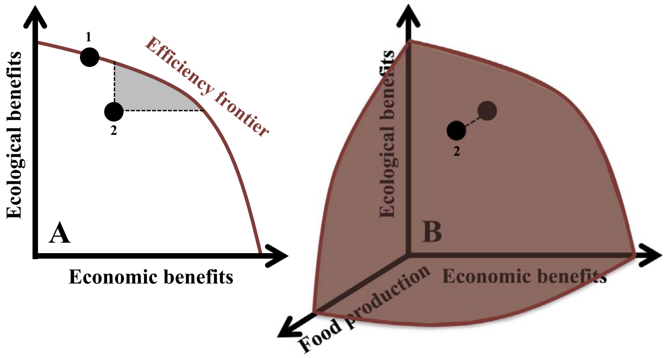

Fig. 1. *Efficiency with multiple objectives.* When managing for multiple objectives, efficiency is a state from which it is impossible to improve in any objective without regressing in at least one other. Panel **A** (in the style of Burgess et al.'s [105] figure 1) illustrates this in a hypothetical scenario with two objectives: economic benefits and ecological benefits. Point 1 is efficient, while point 2 is not—any outcome in the gray shaded region improves upon point 2 with respect to both objectives. Panel **B** illustrates how it is possible for a point that appears inefficient when considering a subset of objectives (point 2) to actually be efficient with respect to a larger set of objectives. Point 2 sits on the 3-D efficiency frontier between economic benefits, ecological benefits, and food production, but its projection into the economic benefits-ecological benefits plane sits below the efficiency frontier, creating the illusion of inefficiency when only considering those objectives and not food production.

How can management better capitalize on win-wins? First and foremost, it has to be aware that the win-wins exist, which requires defining objectives and quantifying tradeoffs up front. For example, in the Marine Life Protection Act process in California [21], a network of more than 100 marine protected areas (MPAs) was designed by evaluating proposals from different stakeholder groups for their expected conservation and fisheries benefits. When a far more comprehensive analysis of all potential MPA networks was later completed, it was clear that every option proposed by stakeholders was quite far from the efficiency frontier. If more options had been explored up front, numerous choices that could have greatly improved both conservation and fisheries outcomes could have emerged [22]. The lesson for other blue growth processes is to explore the full range of potential options to avoid false tradeoffs and enhance the chance of finding win-wins.

It is also important to consider uncertainty when quantifying tradeoffs and designing solutions. Regardless of stakeholder risk preferences, strategies that appear efficient in deterministic projections often turn out to be inefficient when accounting for uncertainty [23]. Structural uncertainties can make some tradeoffs difficult to quantify precisely. In fisheries, management strategy evaluation (MSE)—which involves simulation-testing candidate management strategies under a wide range of possible states of the world—has become a popular approach to quantifying tradeoffs under both structural and parameter uncertainties, and designing robust and resilient management [24]. Nothing about the concept of MSE is specific to fisheries—it could be applied to more general blue-growth frameworks.

2.2. The data you have can do more than you think

Data limitation is often regarded as one of the greatest obstacles to science-based management of complex systems. It is difficult to design improvements to a system's management if the current state is poorly understood, and it is difficult to quantify tradeoffs if the data needed to parameterize models of system interactions are unavailable. The more complex the system to be managed—in terms of the number and nature of both human uses and ecological interactions—the greater the information required for management. Given the cost and capacity associated with collecting data, science-based management should focus on optimizing the use of existing data and should evaluate the importance of new data explicitly within a value-of-information framework.

Recent advances in data science and data-limited assessment have demonstrated how much additional information can be squeezed out of existing data. Four sources of such underappreciated information in data (illustrated in Fig. 2) are briefly discussed below.

2.2.1. If two systems are similar, information from one has value in the other

The world is a complex place but similarities between systems often allow data from one system to carry information that has value in others (illustrated in Fig. 2A). Many of the recent efforts to assess the status of data-limited fisheries have relied on this property. Costello et al. [19,25] and Thorson et al. [26] used regression analyses to identify correlations between the statuses of assessed fish stocks (i.e., how depleted and heavily fished they are) and their catch histories and biological properties. From these correlations, they predicted what the status of *un*assessed fish stocks might be based on observed catch histories and biological properties. Similar methods have been used to identify characteristics of species, ecosystems, and economies that correlate with conservation threats (e.g., [27–33]). These patterns can be used to identify conservation and monitoring priorities in data-poor systems. Natural experiments are another powerful method for squeezing information out of cross-system data. For example, turtle bycatch researchers often compare vital rates of fished and unfished populations to infer fishing mortality (e.g., [34]). Economists often compare similar systems across space or time—in a pseudo-experimental manner—to infer causal effects of either policy interventions or other phenomena on outcomes of interest (e.g., Hsiang et al.'s [35,36] analysis of the effects of climate change on armed conflict; see Section 2.4 below for other examples; see Imbens and Wooldridge

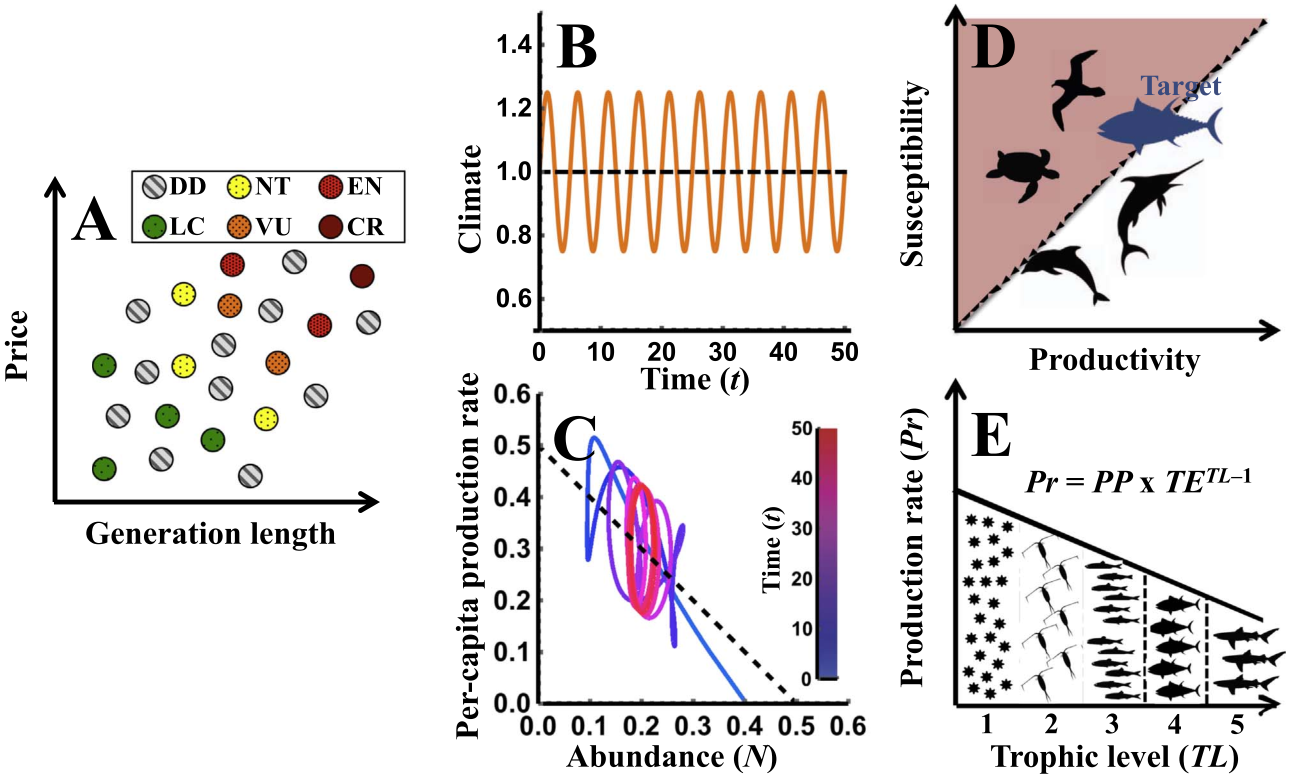

Fig. 2. *Making data go further***.** Panel **A** shows a hypothetical example (based on [30]) of using transferable information from similar data-rich systems to form hypotheses about data-poor systems: Price and generation length are found to correlate with conservation status for a set of harvested species (LC=Least Concern, NT=Near Threatened, VU=Vulnerable, EN=Endangered, CR=Critically Endangered). The relationship suggests that, among the Data-Deficient (DD) species, extinction risk is most likely to be found in those with long generations and high prices. Panels **B** and **C** show an example (based on [7]; same model as their figure 3A, B, with the climate cycle adjusted as shown in **B**) of how one process (climate) driving the other (the production rate of a fish stock) embeds information about the driving process (climate) in the time series of the driven process (production), but not the converse. In **C**, the residual in production, relative to its best-fit relationship (dashed) to abundance (*N*), reflects the residual in climate relative to its mean (dashed line in **B**). However, the state of climate (orange in **B**) carries no information about abundance (*N*), and little information about production. Panel **C** also demonstrates how a lower-dimensional model fit to data from the full system (dashed line) can provide useful, if not exact, descriptions of lower-dimensional relationships (in this case, abundance and production). Panel **D** shows a hypothetical example of using relative measures of productivity and susceptibility to a fishery (see [45]), comparing bycatch species (turtles, marine mammals, billfish, birds) to the target species (tuna) (species in the red region have greater susceptibility/productivity ratios than target species). Burgess et al. [46] showed that, if economics make the long-term status of the target species predictable in absolute, the long-term statuses of the bycatch species are predictable in absolute by extension. Panel **E** illustrates an example of a macroecological pattern that can be useful in data-poor marine management—the relationship between biomass production rates at different trophic levels (i.e. levels of the food chain) and the transfer efficiency (TE, which is between 0 and 1) between trophic levels.

[37] for review).

2.2.2. *Measurements of a system component carry information about all components influencing it*

If a variable (such as the population size of a species) is influenced by other variables (such as climate or another species' population size), then measurements of the state and dynamics of the first variable also carry information about the states and dynamics of the other related variables (Fig. 2B,C).

This principle underpins Sugihara and colleagues' recent innovations in nonparametric forecasting and causality detection (e.g., [38–43]). For example, Sugihara et al. [39] were able to infer that climate (rather than inter-species competition) is the central driver of sardine-anchovy cycles in the eastern Pacific, by demonstrating that time series of both sardine and anchovy abundances can accurately forecast/hindcast sea-surface temperature. In contrast, sardine and anchovy abundance time series have much lower ability to forecast/hindcast each other.

A second consequence of the system-wide information carried in measurements of subsets of complex systems, is that models do not need to explicitly incorporate every aspect of the system to predict tradeoffs between objectives—or responses of system components to pressures—with reasonable accuracy. This possibility arises from the fact that when a model is fit to data—no matter how reductionist the model is—the data are produced by the true system in all its complexity, and therefore parameter estimates capture some of that complexity (Fig. 2C). Burgess et al. [7] review (in a fisheries context) the conditions that promote or prevent complex systems from being abstracted in this way by fitted models of their subsystems.

2.2.3. *If multiple states or processes can be measured relative to one another, only one must be measured in absolute*

In data-poor systems, it is very often the case that relatives are easier to measure than their corresponding absolutes. For example, it may be easier to measure that species X is twice as abundant as species Y than it is to measure the total biomass of either species. It may be easier to measure that three times as many whales of a particular population are killed by ship strikes as are killed by bycatch than it is to measure the total number killed by either stressor. It may be easier to measure the relative fishing mortality rates of two species in a multi-species fishery than it is to measure the absolute mortality rate imposed by the fishery on either one.

Relative measurements often have underappreciated value: If relatives can be measured comparing several components or processes to one another, absolutes only need to be measured for one such component or process to infer absolutes for the rest. In mathematical terms, a vector can be either thought of as a list of its components' magnitudes or it can be thought of as a direction (which specifies the components' relative magnitudes) and a single magnitude.

For example, threatened species often face multiple threats and stressors, only a subset of which can be quantified in absolute. For example (see [44]), the mortality to large marine mammals caused by fisheries bycatch and ship strikes is generally much easier to measure than the mortality caused by pollution and prey depletion. However, the relative importance of all threats to a species' population growth can be approximately estimated via structured expert surveys (see [106]). Combining these estimates of the absolute impacts of one or two threats with estimates of the relative impacts of all threats provides estimates of the absolute impacts of all threats [106] . Estimating the status of various species in a multispecies fishery provides another example. Measurements of species' relative productivity and catch can provide estimates of the fishery's relative impacts on the different species (e.g., [29,45]). From this, the absolute impact of fishing on all species can be inferred (or predicted) from an estimate (or forecast) of the absolute impact of fishing on any one species [46] (Fig. 2D).

2.2.4. *High-level first principles can restrict the range of alternative hypotheses to evaluate*

Any kind of data analysis can be thought of as a means to compare the plausibility of various hypotheses about the system (e.g., hypotheses about the system's structure, its state, or both). The smaller the scope of possible hypotheses, the fewer data are needed to understand the system. This is why, for example, models with fewer parameters can be estimated with fewer data.

High-level first principles are one often-powerful way to restrict the scope of possible hypotheses to be compared in data-limited systems. Examples of first principles used in ecosystem models are: mass balance (where there is strict accounting of total biomass in the system, e.g., [47]), metabolic or bioenergetic theory (where feeding rates, reproduction, and trophic transfers are based on strict energetic accounting, e.g. [48,49]), size- or niche-based species-interaction rules (e.g. [50], and others deriving from it [5]). For a simple example (Fig. 2E), bioenergetic accounting allows measurements of trophic transfer efficiencies and primary production to translate into available production estimates for all trophic levels (see [51] for review), which can be compared with catches—even if biomass is not known—to assess ecosystem-wide fishery sustainability [52].

Many marine systems are data poor, but across the world the information that has been extracted from existing data is probably still only a small fraction of the information those data contain. In fact, the dramatic recent increase in demand—in both academia and the private sector—for data scientists and synthesizers is evidence of this untapped information. It suggests that in many systems there is very high return on investment available in squeezing new information out of old data.

2.3. *Engage stakeholders, but do it right*

Effective stakeholder engagement is an essential pillar of managing blue growth, particularly in data-poor and governance-poor contexts. Engaging stakeholders is essential to understanding their objectives, and it increases local information and capacity. Historically, natural capital and ecosystem services have been undervalued, in part due to a lack of understanding of the value of these goods and services to different groups of stakeholders [53]. Scientists and managers have also often undervalued or overlooked local people as valuable sources of information and capacity [54,55].

Citizen science and local ecological knowledge can provide a valuable means of accessing new data. A citizen scientist is a volunteer who "collects and/or processes data as part of a scientific inquiry" [56]. These citizen scientists are tweeting about snowfall, playing cognitive video games and helping researchers solve previously intractable problems [57]. By engaging the public, researchers and managers can collect vastly more data, and the data these amateurs produce can be just as reliable. For example, in a national citizen science program in Australia, marine debris data collected by primary and secondary students and teachers were just as high quality as the data collected by researchers, and the data were also collected as efficiently [58]. An evaluation of 83 citizen science case studies in peer-reviewed literature found that citizen science can produce high levels of citizen engagement and can be a cost-effective approach to collecting essential monitoring data [59]. Crowd-sourcing can also be a source of innovation for solutions and new ideas in building a blue economy. The "Blue Economy Challenge" [60], for example, offers up funding for promising solutions to three different challenges in aquaculture development: 1) rethinking feed for aquaculture, 2) new ocean products, and 3) sustainable design.

On a more local level, resource users can provide critical information to improve natural resource management and marine ecosystem health [61]. Indeed, the concept of using local ecological knowledge in fisheries has been around for decades. For example, older fishers can be the sole providers of historical information on changes in local fisheries and marine environmental conditions in data-poor fisheries where long-term datasets are not available; fishers can also provide critical information on differences in the behavior and abundance of target species based on tides or habitats and how these influence fishing strategies [62]. Fishers can be the first to notice signs of trouble, as was arguably the case with the famous early-1990s collapse of northern cod (*Gadus morhua*), where inshore fishers noticed signs of stock decline several years before it became evident in industrial catches [63]. For these reasons, many industrial fishery management institutions try to formally incorporate local knowledge through multi-stakeholder advisory bodies (e.g., in the U.S., e.g. see [64], and Canada, e.g. see [65]). This can be challenging in practice, as was the case in the northern cod example, where key information about uncertainty in the stock's health and status was not effectively transferred to management until it was too late [63].

In addition to the value of the information from local sources, managers may be able to learn from the experiences of other communities that rely on local ecological knowledge. The management systems in these communities can resemble an ecosystem-based approach, managing based on their in-depth knowledge of both resource and ecosystem dynamics [66]. Berkes et al. [67] examined the role of local ecological knowledge in managing ecosystems and found that some ecosystem-based management practices such as multiple species management had been abandoned by conventional resource management, but were preserved by local and traditional communities. These ‘traditional’ systems of management may be more progressive than current conventional systems in some respects, and could be good models to replicate when integrating fisheries management with other marine uses in a broader blue growth strategy.

Engagement of stakeholders early in the development of new ecosystem-based management systems can enhance the likelihood of buy-in, identify the full range of objectives, and build capacity for adaptive management and blue growth in the future. In a study of 105 ecosystem management projects, a collaborative process was found to be the most important factor in enabling successful project outcomes [68]. Lessons learned from marine spatial planning (MSP) initiatives demonstrate the value of engaging with stakeholders early and often. During the emergence of national marine spatial planning efforts in the United States, Gopnick et al. [69] engaged diverse stakeholders on the topic of MSP and all participants agreed that government planners need to engage outsiders earlier, more often, more meaningfully and through an open and transparent process. Incorporating fishers' priorities and data in marine protected area design initiatives have been shown to reduce the costs of MPA planning and improve the efficiency and defensibility of planning outcomes [70].

It is also important to emphasize that effective stakeholder engagement is challenging and resource intensive, and without real investment or proper design, the benefits could be minimal or nonexistent. For example, nominal efforts to engage stakeholders through legally bound processes such as public hearings and comment procedures are ineffective, as they typically do not genuinely engage participants nor improve the decision making processes [71]. Stakeholder engagement processes that allow political filters to be placed on the scientific information reaching decision makers can undermine evidence-based management (e.g., [65]). Effective collaboration and stakeholder engagement face other challenges, including restricted funding, institutional bureaucracy, limited timeframes for collaboration, initial lack of local knowledge on the part of foreign partners, and differences in working practices [72]. To be successful, stakeholder engagement processes should be designed to integrate scientific guidance into decision-making. Rassweiler et al. [22] evaluated how effective stakeholder-driven plans for marine reserve design were in achieving economic and conservation goals, and found that stakeholder-generated plans failed to achieve their objectives in the absence of strong scientific guidance, suggesting an effective mechanism where scientists and stakeholders can productively engage with one another.

Despite these challenges and up-front costs, the dividends from effective stakeholder engagement can be significant. When stakeholders are engaged in a meaningful way, managers can access more and better data, dramatically improve their understanding of the systems, and improve the likelihood that the institutions they are investing in will be supported in the long term.

2.4. Measure your impact and learn as you go

Effectively measuring the impact of an intervention requires careful planning before the intervention is undertaken. Measuring impacts has at least three benefits. First, it allows scientists and managers to assess the efficacy of an intervention. Second, it may facilitate addressing broader scientific questions that can help guide future interventions in other locations. And third, the process of iteratively learning and revising an intervention operationalizes adaptive management.

In the social science literature—particularly in economics and development studies—tools for impact measuring are collectively grouped under various umbrella terms, such as ‘rigorous program evaluation’ or ‘impact monitoring and evaluation’. For the purposes of this article, the terms and definitions are less important than what tools actually *do*. Their ultimate goal is to identify causal effects relative to a plausible counterfactual. In other words, can it be shown that an intervention produced the intended result and can any competing explanations confidently be ruled out?

In practice, researchers typically measure impacts and determine causal effects by appealing to some form of randomization. That is to say, researchers ideally want to compare two systems where—either by chance or design—each had an equally good chance of receiving the “treatment” *a priori*.[1] As an example, consider two open-access fisheries that are virtually identical to each other in all major respects (e.g., target species, fishing gear, fisher incomes). Now imagine that a local politician decrees a management intervention be established in only one of the fisheries based on a lottery draw. The importance of the lottery from a scientific perspective is that it randomly assigns the intervention to one fishery in a way that preserves the other fishery as a counterfactual. That way, even if harvests decline in the intervention fishery due to some unforeseen shock, the intervention can still be regarded as a relative success if harvests are better than in the open-access fishery. The key assumption here is that the intervention fishery and the open-access fishery would have been similarly affected by the shock or any other exogenous factors. Any meaningful difference in fishing outcomes can therefore be attributed to the intervention.

The above lottery example is admittedly contrived. However, the same basic principle underpins virtually all of the methods that can are used for measuring impacts and determining causal effects. These include empirical and statistical approaches such as randomized control trials (RCTs), difference-in-differences (DiD), regression discontinuity design (RDD), and propensity score matching (PSM). In the absence of statistical measures and data availability, it is also possible to simulate computer-based counterfactuals using biological, ecological or economic models. Listing the relative strengths and weaknesses of these various approaches is beyond the scope of this article; a thorough discussion may be found in [73,74], among many others. The main point is that all of these methods invite a careful consideration of the factors that allow causal inferences to be made. At the same time, it is important to acknowledge that some methods (e.g., RCTs) are more scientifically robust than others. The price of such improved robustness is that additional steps and design planning are required at the outset of a project. Deliberately incorporating a counterfactual scenario into the incipient design process makes it much easier to measure true

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[1] Much as it does in a medical context, ‘treatment’ here describes a system, group or individual that is exposed to some intervention or policy action. Similarly, the words ‘treated’ and ‘control’ are respectively used to distinguish between systems that did receive treatment and those that did not (i.e. the counterfactual).

causal impacts down the road.[2] In contrast, finding suitable control sites and counterfactual examples for a project *post hoc* typically involves a large amount of luck and added uncertainty.

The preceding paragraphs describe the 'how' of causal inference and measurement; it is equally important to address the question of 'why'. Why should scientists and managers spend so much time trying to identify true causal effects? The short answer is that management has limited resources. Without an understanding of causality, enormous resources could be wasted on interventions that managers erroneously believe will lead to desirable outcomes, only to later learn that no such effects accrue. More than just brute economics, however, it is also *ethics* that demand the measurement of management impacts. Management seeks results that possess scientific merit for wider application and can materially improve the lives of stakeholders. Moreover, carefully evaluating causal links between interventions and their intended outcomes ensures that valuable taxpayer and donor money is not wasted on ineffectual interventions. These ethical dimensions are particularly germane, because they push back against the notion that using comparison sites or control groups—which by design would not receive potentially beneficial treatment—necessarily violates ethical norms [76,77]. Such near-term tradeoffs are undoubtedly unfortunate. Yet, ultimately blue growth is concerned with the long-run viability and vibrancy of all the world's oceans and coastal communities.

As a final word on this topic, it is worth noting that failing to incorporate sound program evaluation at the conceptual outset of a project can undermine even the best of intentions. The development economics literature in particular offers up many cautionary tales. As one high-profile example, a vigorous scientific debate has for years embroiled the Millennium Villages Project (MVP), which ambitiously aims to provide scalable solutions that would bring tens of thousands of communities out of poverty [77]. Much of the criticism aimed at the MVP is rooted in the project's decision to omit comparison (i.e. control) village sites—in part for ethical reasons, in part for practical reasons. However, this decision ultimately makes it difficult to measure the project's actual impact on poverty reduction relative to a plausible counterfactual. Following earlier criticism of purported MVP findings (e.g., [78,79]), a much-feted article in a leading medical journal [80] was quickly undermined by a critique [81]. This subsequently led to the MVP researchers issuing an error acknowledgement and partial retraction [82]. The affair further elicited an editorial comment in the journal itself [83] and much discussion elsewhere [84,85]. Projects like the MVP certainly have laudable goals and face important practical constraints, but ocean practitioners may nonetheless hope to avoid such controversy in their pursuit of efficient and sustainable blue growth.

2.5. *Design institutions, not behaviors*

Blue growth should focus on designing institutions, rather than imagining that managers can directly design stakeholder behavior. For the purposes of this article, a 'behavior' is what the manager wants stakeholders to do—for example, how hard to fish, how much to produce, how little to pollute. Institutions are the social structures (e.g., regulations, norms, markets) under which stakeholders choose their behaviors. Managers do not directly control behaviors, but they can indirectly influence behaviors by changing institutions.

Despite this, resource management questions in the oceans are often posed in terms of behavioral design rather than institutional design. Fisheries science, for example, often tries to identify which fishing patterns (in terms of intensity, location, gear choice, or target species) satisfy criteria such as optimality (e.g., [19]), Pareto efficiency (e.g., [5]), improvement from status quo (e.g., [86]), or coviability (e.g., [87]) with respect to one or more objectives (e.g., profits, food production, conservation). Other types of behavioral design in marine planning include pollution intensities, and spatial allocations of shipping, fishing, tourism, and other ocean uses.

Yet management does not directly control any of these behaviors; it directly influences only the institutions, which in turn influence the behaviors. Institutions in fisheries, for example, include catch limits, size limits, fuel subsidies, MPAs, catch shares, social norms, and other forms of governance [88]. These only indirectly influence the fishing pattern via fisher incentives. Even regulations (e.g., catch limits, size limits, MPAs)—which influence the fishing pattern seemingly directly—are only influential insofar as they are enforced by other governance institutions (e.g., fines and other forms of punishment, loss of community standing). Different institutions—even those designed for the same objectives—can vary widely in the behaviors and outcomes they produce; as well as their associated costs, side-effects, and resilience to unexpected shocks. Fulton et al. [89], for example, review instances in which fisheries management objectives were undermined by policy design flaws. In sustainability science, the cap-and-trade vs. carbon tax debate provides a particularly salient example of two institutions with exactly the same objectives often producing starkly different outcomes (see [90,91] for review).

Thus, institutional design should be central in managing blue growth. When behavioral design is overemphasized instead, it tends to promote command-and-control management. For example, if scientific analysis suggests a particular fishing pattern is ideal for a fishery management objective, a temptation is to directly prescribe the ideal fishing pattern through a patchwork of catch limits, gear restrictions, and temporal and spatial closures. Yet more careful analysis often finds that different, simpler institutions perform better. For example, the U.S. west coast groundfish fishery perennially faces the challenge of keeping bycatch of a handful of overfished species (e.g., canary rockfish—*Sebastes pinniger*) to sustainable levels while still taking advantage of the high productivity of other target species (e.g., Dover sole—*Solea solea*) [92]. In 2011, this fishery transitioned from a patchwork of command-and-control regulations to a market-based catch-share management system and significantly reduced the ratio of bycatch: target species catch as a result [93].

2.5.1. *Key institutional design features*

Designing institutions well is important, but what makes an institution well-designed? This is a core research theme in economics and other social sciences, and many key design elements have been identified for governing common pool resources (see [94–96] for reviews). A common theme among successful institutions is that they typically correct market failures and/or promote resilience.

For example, in their review, Dietz et al. [96] argue that ideal sets of institutions are diverse and layered, have some degree of redundancy, and promote both dialogue among stakeholders and opportunities for learning and change. Each of these characteristics promotes resilience. Resilience—which Walker and Salt [97] define as "the capacity of a system to absorb a disturbance and still retain its basic function and structure"—is an essential design objective of resource management in an uncertain and changing world, a world experiencing environmental shocks and unprecedented environmental conditions at an increasing rate [98]. Even in an unchanging system, a lack of understanding of the system's complexity can appear to create shocks, which really resulted from forecasting and estimation errors within models. Institutions with resilience to both of these sources of shocks will be needed to sustain blue growth in the long term.

Market failures occur when the private actions of individuals (or firms or regional governments, in some settings) aggregately fail to achieve an efficient resource allocation at a larger scale (e.g., at the societal level, at the international level, across time periods). This can occur for a variety of reasons, one of the most common of which—in

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[2] This is not to say that RCTs and similar methods are *necessarily* superior to other approaches. See Deaton [75] for critical review.

common-pool resource settings—is externalities. An externality occurs when an individual, group, or firm's actions have consequences for other individuals, groups, or firms, and these consequences are not accounted for in decision-making [99]. For example, fishers in an open-access fishery will deplete the stock below the profit- or yield-maximizing level because they do not factor the benefits of catch for other fishers into their fishing decisions.

Institutions that successfully align incentives in the face of externalities often do so in one (or both) of two ways: (i) They create social conditions under which direct and indirect reciprocity make it in the best interest of individuals (or cohesive groups such as firms or countries) to take the externalities of their decisions into account (see [94,100,101] for review of some such social conditions). For example, members of a closed, frequently interacting social group will be less likely to behave callously or unscrupulously towards each other than they will towards strangers, as such behaviors might be reciprocated against them in the future (e.g., see [101,102]). Similarly, it is likely easier for countries that already have close bilateral relations and extensive trade to develop and implement new cooperative resource management agreements. Close reciprocal relationships formed through repeated interactions generate sentiments of trust; not surprisingly, trust is often cited as an important element of well-functioning institutions (e.g., [96]). (ii) Institutions can align incentives by creating and mediating explicit mechanisms (e.g., legal) to internalize the externality, where they also have legitimate power over all parties involved to enforce these mechanisms. For example, catch shares in fisheries align incentives by creating and enforcing formal property rights for individual fishers [103]. Territorial Use Rights for Fishing programs (TURFs) provide spatial property rights to communities, and work best when the communities internally have clear boundaries and social norms enforced by reciprocity or leadership [104].

One of the major challenges for blue growth will be designing robust and resilient institutions at the multinational level; most marine ecosystems span multiple countries' exclusive economic zones (EEZs) and/or international waters. There are still relatively few international organizations with the power and legitimacy to enforce explicit externality-internalizing mechanisms; the World Trade Organization (WTO) perhaps provides one example. However, globalization continues to expand relations, trade, and trust among countries, and this has been an effective starting point for some ambitious fisheries and marine governance initiatives, such as the European Union (E.U.) Common Fisheries Policy—built on top of a much larger framework (the E.U. itself) of international trade and cooperation. Continuing to leverage strong pre-existing bilateral relationships between countries will likely be important to future progress towards blue growth, especially in the near term.

3. Conclusion

Blue growth will require reducing or eliminating externalities in a complex system, despite limitations on data and capacity. These externalities will be found across sectors, communities, or countries, and across time. Addressing the externalities will require designing institutions that can be locally supported and feasible. Designing such institutions will require as much knowledge as possible of stakeholders' objectives and the tradeoffs between these objectives. In a world of limited data and resources, it is important to extract as much information as possible from the data collected. Involving stakeholders in information-gathering and management processes illuminates their objectives, puts their local knowledge of the system to use, and creates the buy-in required for new institutions to be successful. Measuring the impact of interventions and learning from their revealed successes and failures makes management adaptive, which builds resilience and reduces long-term costs. This is the basic logic of the pragmatic approach to blue growth envisioned here.

Acknowledgements

We thank the Editors of this special issue for their vision, hard work, and feedback in the process of putting the issue and our manuscript together. We thank the attendees of a University of Washington seminar, especially Cole Monnahan, for useful feedback on some of the ideas presented here; and two anonymous reviewers for comments on an earlier draft of the manuscript. We acknowledge funding from the Waitt Foundation (SB130076) and the Ocean Conservancy (SB150168).

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