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Sea sick? Setting targets to assess ocean health and ecosystem services

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Abstract. The benefits provided by a healthy ocean are receiving increasing attention in policy and management spheres. A fundamental challenge with assessing ocean health and ecosystem services is that we lack a scientific framework for expressing ecosystem conditions quantitatively in relation to management goals. Here we outline and operationalize a conceptual framework for identifying meaningful reference points and quantifying the current ecosystem state relative to them. The framework requires clear articulation of management goals and is built on a review of current scientific understanding and assessment of data availability. It develops a structured approach for choosing among three classes of reference points, including: (1) functional relationships that establish the ocean state that can be produced and sustained under different environmental conditions, (2) time series approaches that compare current to previous capacities to obtain a particular ocean state in a specific location, and (3) spatial reference points that compare current capacities to achieve a desired ocean state across regional (or, if necessary, global) scales. We illustrate this general framework through the lens of ocean health defined in terms of a coupled social-ecological system, with examples from fisheries, marine livelihoods, and water quality in the USA. Assessment of ocean health and ecosystem services can be significantly influenced by the choice of indicators used to track changes in a management goal, the type of reference point selected, and how one measures the distance of the current state from the reference point. This framework provides flexible, standardized methods for evaluating ocean health and ecosystem services that can advance important components of ecosystem-based management, including marine spatial planning, ecosystem service valuation, and integrated ecosystem assessments.

Key words: ecosystem-based management (EBM); ecosystem services; indicator; ocean health; Ocean Health Index; reference point; target.

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Introduction

The ability of the oceans to deliver the benefits people desire is in question. Many marine fisheries are in crisis, natural and man-made disasters have devastated coastal habitats, and signals of climate change's rapid advance are pervasive (Lotze et al. 2006, Worm et al. 2009, Doney et al. 2012). At the same time, many coastal regions are characterized by booming tourism industries, growing networks of species-rich marine reserves, and recovering populations of iconic species (McLeod and Leslie 2009, Gaines et al. 2010, Lotze et al. 2011). In all of these diverse examples, people are inextricably part of how ocean condition is measured and interpreted. Ecosystem-based management (EBM) has emerged as a promising way to keep track and manage ocean condition because it considers species, habitats, sectors, and user groups collectively (Leslie and McLeod 2007, McLeod and Leslie 2009). With this development, scientists and resource managers are under increasing pressure to provide report cards that convey information about progress toward a healthy coupled social-ecological system, inclusive of ecosystem structure, function, and services. It is a daunting assignment because while there are countless ways to develop status assessments, not all of them show fidelity to principles of objectivity, and an overarching framework is lacking.

The exact definition of ocean health varies across locations and stakeholders, but it often consists of a diverse set of management goals related to how people use and value the marine environment (UNEP 2006, EPC 2008, PSP 2008, Commonwealth of Massachusetts 2009, IOPTF 2010). The assumption behind setting ocean management goals is that a community has a vision for a desirable system and the various intrinsic and utilitarian benefits it can provide, such as the existence value of coastal habitats teeming with diversity or the utilitarian value of waters clean enough to allow recreation. In order to serve the policy, management, and communication purposes for which such goals are intended, concrete targets must be defined. Targets describe the vision for a desirable system by translating broad management goals into quantitative expressions that in turn allow direct assessment of ocean status. They can range from preventing extinction of threatened species (CBD 2011) to detailed descriptions of the intent to restore a specified area of habitat (PSP 2011, SFBJV 2011) or catch an explicit number of metric tons of fish (NMFS 2009). As such, targets are a hallmark of successful management and policy planning processes (CMP 2007).

While the need to set targets to assess ocean status is clear, little attention has been devoted to developing consistent and practical standards for setting targets across a wide diversity of management goals for the ocean. This is particularly surprising given a growing number of EBM initiatives that challenge scientists to provide guidance that extends beyond single users and single sectors (Leslie and McLeod 2007, Levin et al. 2009, Foley et al. 2011b). Setting targets to facilitate status assessment has long been part of the lexicon of conservation and management initiatives related to marine fisheries and water quality (Kimbrough et al. 2008, NMFS 2009), but in other sub-disciplines they are less commonplace. In addition, although a consistent body of literature has focused on criteria for selecting appropriate and useful ecosystem indicators (Rice 2003, Jennings 2005, Niemeijer and de Groot 2008, Kershner et al. 2011) there have been few efforts to develop a clear and generalizable set of guidelines to navigate from scientific understanding, around the obstacles associated with data limitations, through to the application of targets and assessment of ocean conditions.

Here we introduce a novel conceptual framework that provides a road map for setting targets and evaluating current ecosystem conditions relative to them. The framework is compatible with different levels of scientific understanding and data availability and emphasizes practical approaches that can be used to evaluate ecosystem status at local, regional, or even global scales. We illustrate it through the lens of ocean health and ecosystem services, using examples from fisheries, marine livelihoods, and water quality in the USA. The three key elements of our framework include: (1) precisely articulating management goals, (2) setting targets, and (3) scaling the current status of management goals relative to those targets. The most conceptually rich and challenging step is setting targets so we address this element in detail.

Conceptual Framework for Assessing Ecosystem Status

Terminology

In this paper we embrace a coupled systems perspective, defining a healthy ocean as one that delivers benefits to people now and in the future (Rapport et al. 1998; K. L. McLeod et al., *unpublished manuscript*). However, we recognize that others define ecosystem health strictly in terms of the structural and functional integrity of the biophysical system, independent of the services provided to people (Costanza et al. 1992, Borja et al. 2012). The framework introduced below is not dependent on our definition of ocean health—it could be applied to track conservation goals and broader environmental management goals. Indeed, our framework is couched in relation to ocean health and ecosystem services, but it is sufficiently general that it could be applied with only minor modifications to assess the status of terrestrial or aquatic ecosystems.

We refer to management goals as broad statements about desired ocean conditions. A target is a point of reference that provides clarity on the specific amount of a marine-derived benefit that is equated with goal achievement. We use the term benefit to refer to all values, inclusive of those that are intrinsic and utilitarian, related to ocean health and ecosystem services. A target reference point is distinguished from another common type of reference point, a limit, which demarcates ocean conditions to be avoided (Jennings and Dulvy 2005). We focus here primarily on targets to create consistency between the language used to frame management goals and the quantitative expressions used to assess status and track progress. However, we recognize that there will be some cases where limits are more appropriate, either because of how the goal is framed or data limitations. In addition, we distinguish the target reference points on which this paper is focused from *management* targets, which are negotiated via policy processes that can be informed by an understanding of scientific and objective reference points (e.g., to ensure precautionary management or to increase the likelihood of achieving a goal). Management targets are always a subjective decision but are most useful and appropriate, we believe, when informed by scientific evidence. Below we use the term targets as shorthand for "target reference points", with the aim of illustrating the role science can play in informing policy processes that set management targets. Targets (and limits) should be measured in the same units as the indicator, or empirical proxy, chosen to measure the state of a management goal.

Precisely articulating management goals

Precise articulation of management goals is essential because it guides the selection of an appropriate indicator for assessing the status of the goal. If management goals are not stated in ways that can be measured with empirical data they forfeit their own utility because there is no way to measure progress towards goal achievement. Furthermore, the specifics of how a goal is framed direct scientific attention to the appropriate currency for the indicator (e.g., biophysical, economic, or social units; Tallis et al. 2012). To that end, it can be advantageous to translate a management goal to a maximization or minimization problem with an objective function so that it is clear exactly how an indicator should be developed to track progress. Indeed, these choices significantly influence the evaluation of a goal's status. For instance, a sustainable seafood management goal could be measured in terms of yields if the goal is focused on maximizing food provision or in number of jobs if the goal is focused on maximizing social and economic welfare. These two goal framings would lead to the development of different targets in terms of both yields and level of employment (Clark 2006). Where necessary, our conceptual framework encourages the reframing of management goals to ensure that the corresponding indicators, and the currencies in which they are reported, accurately portray the intent of the goal as it is stated (see *Applying the Framework to Ocean Health and Ecosystem Services*).

Setting targets

Our framework incorporates SMART principles for target setting: Specific (to the management goal), Measurable, Ambitious, Realistic, and Time-bound (Perrings et al. 2010, 2011). We interpret time-bound as either a policy decision that defines an explicit deadline by which a target is met, or, more frequently in the examples we present below, the time period over which scientific analysis focuses in identifying an appropriate target level. There is tension inherent to setting a target that is both ambitious and realistic. It is likely that policy processes will recognize the former in order to motivate actions that will facilitate the achievement of the management goal, but settle on a management target that is somewhat more conservative than the ideal reference point. In this paper we focus on three scientific techniques that can be used to inform such choices.

We developed a set of decision trees (Fig. 1) that provide guidance for choosing among three types of target reference points. They describe targets that compare the current ecosystem state with its (1) ideal state given an understanding of its functional relationship with environmental conditions, (2) historical status, and (3) maximum value in the region or across the globe. We refer to these three approaches as those based on functional relationships, time series approaches, and spatial comparisons. Below we provide a road map for navigating the decision tree and explore each of the three techniques with examples. Note that all three types of targets require that (1) the management goal is articulated precisely so that the appropriate indicator, and indicator currency, is used and societal preferences are accurately represented; (2) scientific understanding about the relationship between the ecosystem state and natural or human pressures is reviewed; and, (3) data sources and their limitations are investigated thoroughly.

Functional relationships

The first type of target (Fig. 1A) is derived from a functional relationship between the indicator of ocean conditions for a goal and natural or human pressures. Functional relationships are particularly useful because they clarify the link between management levers and the status of a goal (Samhouri et al. 2010). Production functions (Nelson et al. 2009) that relate the amount of an ecosystem service to social or ecological predictor variables represent one category of functional relationships that can serve this purpose. If an empirical or theoretical functional relationship is available, it can be used to determine a reference point for the amount of a benefit that can be expected from the system. This process is facilitated by the fact that functional relationships are often associated with thresholds and optima.

To derive an appropriate target level for an indicator of ocean conditions from a functional relationship, one should first test for linearity. A linear function does not directly suggest a reference point, but still can be used to set a target if there are established legal regulations or social norms (common standards of practice) associated with the relationship (Fig. 1A). For example, U.S. EPA policy sets a threshold for the acceptable number of illnesses due to swimming and uses a linear functional relationship between swimming health safety and the concentration of *Enterococcus* bacteria to establish the bacterial concentration at which that limit reference point occurs (Cabelli et al. 1983, http://www.cdph.ca.gov/HealthInfo/environhealth/water/Pages/Beaches.aspx). They base their recommendation for a target level of water quality for marine recreation on that limit.

If a linear functional relationship is identified, but there is no legal or social standard to justify a specific target, a science-based, stakeholder-driven process can be used to identify an acceptable target (Gleason et al. 2010). For example, if the relationship between marine reserve size and proportion of a fish population protected from fishing is assumed to be linear (Shanks et al. 2003), a process of negotiation among fishermen, conservationists, and other interested parties can be used to determine appropriate guidelines for reserve size or total area designated for protection.

A nonlinear functional relationship can be used to set a target based on an optimum level or an established threshold (Fig. 1A). Optima and thresholds can be used directly, or with modifications such as precautionary buffers. For example, surplus production and yield-per-recruit models agree in a qualitative sense that fisheries yield should peak at an intermediate level of fishing pressure (Jennings et al. 2001). This maximum is frequently referred to as the maximum sustainable yield (MSY). Under the U.S. Sustainable Fisheries Act of 1996, MSY is defined as a limit reference point. It is reduced based upon ecological, economic, or social considerations to create a target harvest level referred to as optimum yield. For European

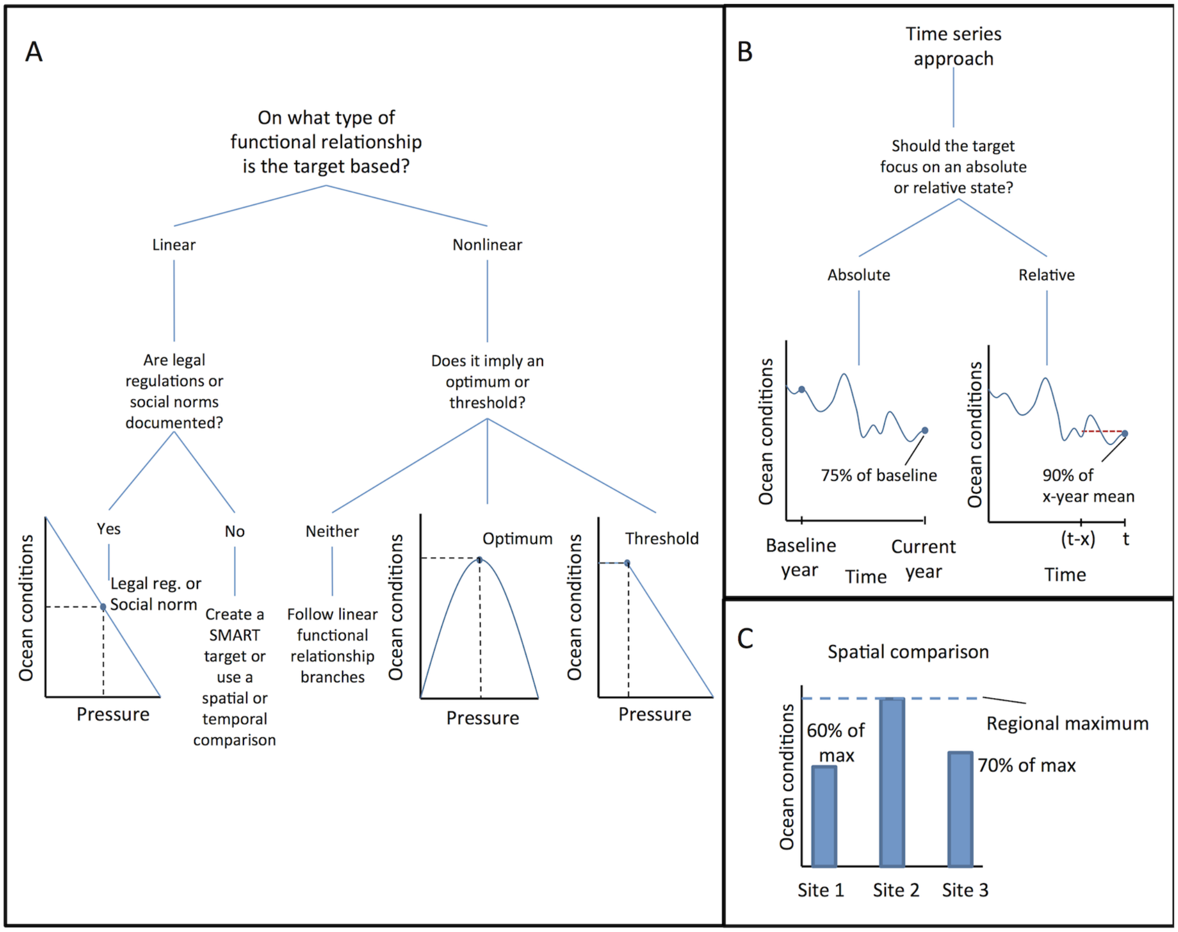

Fig. 1. Decision trees for choosing between three types of targets based on (A) functional relationships, (B) time series approaches, and (C) spatial comparisons. In (A), with linear functional relationships, a target (represented by the point on the line) can be set based on existing legal regulations, documented social norms, or using the SMART principles. The choice of the target level is based on societal values and the target may be somewhat scientifically arbitrary. For a nonlinear functional relationship with an optimum, the ocean condition related to the management goal is diminished on either side of the inflection point; in the case of a nonlinear functional relationship with a threshold, the threshold occurs where there is a pronounced change in the slope of the relationship between ocean conditions related to a management goal and a pressure(s). In (B), the current ocean conditions related to a management goal can be compared to the absolute ocean conditions during a fixed period in the past, or baseline. In this hypothetical case, the current state is 75% of the baseline. Alternatively, the current ocean conditions related to a management goal can be compared to the ocean conditions during a period in the past that slides forward through time. In this hypothetical case the current state is 90% of the average state over the previous x years (moving window = x years). The appropriate value of x depends on socio-cultural considerations related to the management goal, the sensitivity of the status evaluation to variation in it (increasing the value of x will reduce the variance of the original data), and the length of the time series. In (C), a spatial comparison sets the target as the maximum ocean conditions in a geographic region. In this example, site 2 has the maximum ocean conditions and would receive a value of 1. The status of site 3 would be considered better (70% of target) than site 1 (60% of target).

fisheries, Froese et al. (2011) recommended a generic, precautionary annual target catch of 91% of MSY.

As an example of a threshold-derived target, contaminant levels in water or seafood can be set based on thresholds in human health indicators. In the U.S., the Mussel Watch program (Kimbrough et al. 2008) samples mussels and other shellfish regularly to compare the concentrations of arsenic, mercury, and other chemicals in their tissues to human consumption recommendations. Many of these recommendations have been informed by thresholds derived from nonlinear dose-response relationships between toxic chemicals and cancer risk in people (e.g., arsenic and skin cancer, EPA 1988; methyl mercury and neurological deformities, Budtz-Jorgensen et al. 2000). The implied Mussel Watch targets for contaminants in shellfish tissues are to maintain compliance with the consumption recommendations, and in principle a buffer could be instituted to ensure that dangerous chemical concentration levels were not exceeded.

Time series approaches

In cases where a functional relationship is unavailable, two scientific approaches remain for setting a target. The first draws on time series (Fig. 1B) to evaluate the current ocean conditions in an individual location relative to conditions in that location at a previous time period. Time series data are used to provide an internal standard against which current conditions are judged.

Our framework emphasizes two types of targets that use time series data (Fig. 1B). The first is a baseline, which focuses on a stationary time period, relays information about what was previously possible in a particular location, and is especially useful for goals in which the desired state occurred at a fixed time in the past. The second is based on a moving window time period, which facilitates comparisons with contemporary conditions and smoothes short-term fluctuations and distortions in time series data (Box et al. 2008). Moving window approaches are particularly appropriate when the intent of a management goal is to prevent declines in the current state relative to a recent time period. They are commonly used to describe the condition of financial markets (e.g., day-to-day changes in the Dow Jones Industrial Average).

Both baseline and moving window targets are challenged by the need to choose an appropriate reference time period (Samhouri et al. 2011), with what is appropriate being guided by SMART principles. For example, we would contend that a reference point of pre-human conditions is not realistic (though others have adopted the pristine state as a target; Borja et al. 2012). Choosing a reference period can be made less arbitrary by (1) attempting to minimize the sensitivity of the status assessment to the selected time period; (2) capturing all of the information available in the time series by ensuring that periods of substantive change are included or by making the moving window of time equivalent to the entire length of the time series; and, (3) following existing precedents. However, even arbitrary choices about the appropriate reference period can be informative, and are used frequently in relation to socioeconomic indicators (TBCB 2001), advances in human medicine (Marshall 2011), and in other contexts. Such targets convey straightforward information about the extent to which ocean conditions have changed through time.

Targets determined via time series approaches are pervasive in marine conservation and management. The current extent of living marine habitats (e.g., corals, seagrasses, mangroves, etc.) is frequently measured relative to the baseline extent (Fig. 1B; Waycott et al. 2009, Valiela et al. 2001, Schutte et al. 2010, Bruno and Selig 2007). For instance, in Schutte et al. (2010), today's Caribbean coral cover was estimated as 82% of a target level based on a 1972 baseline. The 1972 baseline was chosen primarily because data availability is extremely limited prior to that time.

Targets based on moving window time series approaches are also common, especially with respect to data-poor fish stocks and human dimensions of ocean health. In the Northeastern U.S., status assessments of data-poor fish stocks such as red hake *Urophysis chuss*, silver hake *Merluccius merluccius*, and a multispecies complex of skates, are based on comparisons of recent biomass to the average biomass of each stock since research surveys began. Thus, the reference period is not fixed; it "moves" to include each additional year in which research surveys are conducted (L. Alade, NEFSC, personal communication). Similarly, the implicit targets for socioeconomic indicators generally tend to invoke constant increases, or at least no reductions, in comparison to recent values (e.g., earnings reports, housing starts, etc.; www.census.gov). An identical logic can be applied to the number of jobs in marine sectors, such that the number of jobs across all marine sectors today should not dip below the average over the recent past (e.g., 3 years; Fig. 1B). This "no net loss" target captures a short-term economic signal (e.g., there are fewer marine jobs because of a fishery closure) rather than a generational change that might result from cultural shifts (e.g., there is less marine employment because people lose interest in maritime-related jobs). It is also in line with other management goals related to the marine environment that stipulate no net loss explicitly (e.g., US National Policy for Wetlands).

Spatial comparisons

The second approach to setting targets in cases where functional relationships are unavailable relies on spatial comparisons (Fig. 1C). Targets derived from spatial comparisons gauge the current ocean conditions in a particular location relative to the current ocean conditions in a reference area(s). Spatial comparisons use logic similar to that of a benefits transfer approach to assessing ecosystem service value (Nelson et al. 2009), in that different locations are assumed to be capable of producing similar ecosystem benefits. In this case, the amount of benefit observed in one location is defined as the maximum and is used to judge the status of a benefit in other locations. Thus, a target based on a spatial comparison relies on an external standard for all but one location (the place with the maximum benefit), under the assumption that if a reference location can attain a certain state, then so can other locations within the study region (Borja et al. 2012).

To estimate a target using a spatial comparison, the current state in each location within a study region is cataloged, the maximum observed benefit is defined as the target, and the status of the benefit in each location within the region is assessed relative to that target value (Fig. 1B). For example, food provision from the ocean comes not just from wild fisheries but also from mariculture. As with terrestrial agriculture, mariculture's status can be measured in terms of the yield from cultured stocks in a particular place. However, there will not be empirical data on the maximum yield that can be achieved for a given species in all locations of interest. As an alternative, inferences about the health of a specific location's mariculture industry can be made via reference to regional (per unit area) potential. Indeed, a similar approach has been used to estimate crop "yield gaps" in terrestrial agriculture (Foley et al. 2011*a*), in the context of conservation planning for ecosystem services (Chan et al. 2006), and to compare fish stock status outside of marine protected areas to status within them (Hamilton et al. 2010).

Choosing the right type of target

There is no simple rubric for choosing the right type of target. Our framework is underpinned by the idea that targets based on functional relationships are ideal, but given data constraints, time series approaches and spatial comparisons may be more appropriate. The intent of a management goal, scientific understanding, data availability, and the degree to which potential targets adhere to SMART principles will largely dictate which type is most appropriate.

We consider functional relationships the premier approach for deriving targets because they provide direct insight into how pressures can be adjusted to achieve management goals and do not rely on relativistic comparisons with other places or previous conditions. At the same time, functional relationships allow for rigorous comparisons of ocean conditions between locations at any one time or between time periods at any one location. In addition, targets based on functional relationships are more likely than time series approaches and spatial comparisons to strike the right balance between ambitious and realistic. Ultimately, functional relationships are the underlying basis for any goal even if it is difficult to define or measure such relationships.

Unfortunately, targets based on functional relationships require a mechanistic and quantitative understanding, involve site-specific knowledge of how pressures influence ocean conditions, and cannot be developed in many places where data are limited. In other words, targets based on functional relationships may not always be measurable or time-bound, even if they are otherwise specific, ambitious, and realistic. Thus in practice it is likely that the other types of targets will be used with greater frequency.

The choice between using a time series approach or spatial comparison to set a target can be made based on an assessment of the strengths and weaknesses of each approach, the needs of the particular application, and the constraints of available data. This decision can be facilitated by evaluating both the quality of the available data (e.g., gaps in time series, poor spatial resolution or replication) and the type of target that is most informative of the progress towards the goal under consideration. Targets based on time series approaches and spatial comparisons do not require a mechanistic understanding of the system, although some knowledge about such relationships can help constrain the temporal or spatial comparisons (e.g., using geophysical constraints to set regional instead of global spatial reference points). As such, they provide relative measures of ocean condition. For example, with targets based on a time series approach, two locations characterized by very different ocean conditions could be assessed with equivalent status if ocean conditions in both places changed by the same proportion over the reference period. Similarly, a target based on a spatial comparison does not reveal whether the location with the maximum state during the observation period approximates the ideal state that a functional relationship would reveal. As for the case of linear functional relationships, time series approaches and spatial comparisons require ancillary information in order to establish what is considered an ideal state. In the absence of such information, these types of comparisons may still be useful at least for tracking relative progress. Therefore, both approaches have utility as practical solutions to the problem of setting targets given the realities of current scientific understanding and data availability.

A target based on a time series has the advantage that it creates an internal standard against which ocean conditions in a location of interest is measured, i.e., it controls for all variables that are specific to a particular location. In that way, it provides a reasonable proxy for the potential of a site to obtain a particular state in the absence of a functional relationship. The choice between baseline and moving window targets, and the choice of a timeframe for each, depends on how the management goal is articulated. A baseline target is appropriate when a management goal is concerned with how much the ocean conditions have changed relative to a previous condition, and a fixed point in time is considered the best available proxy for the achievable potential of a site. However, a baseline target focused too far in the past may tend to be more ambitious than realistic. A moving window target is appropriate when a management goal is focused on contemporary management effectiveness and conditions in the immediate past provide relevant information about either the desired state or stability of conditions over the timeframe encompassed by the window. However, a moving window target may be more realistic than ambitious. Disadvantages of targets based on time series approaches include the need for site- or regional-specific time series data, the subjectivity involved with choosing an appropriate reference time period, and the need for knowledge about longer-period cycles (e.g., Pacific Decadal Oscillation) that can influence possible reference values.

Targets based on spatial comparisons can be advantageous because they require data only from the current time period and permit direct, straightforward comparisons among locations. In addition, they are grounded in the reality of what is possible given current productivity regimes, human population densities, levels of development, legal and social norms, and financial resources (cf. Foley et al. 2011*a*). However, this grounding comes with some important caveats. A spatial comparison creates an external standard against which ocean condition in a location of interest is measured. Thus, it assumes that what is possible in one place is possible in others, which may not be true for either ecological/biophysical or human/social reasons. Another weakness of the spatial comparison approach is that it assumes that the regional potential maximum state at any time and the regional maximum today are one and the same. As a result, a target based on a spatial comparison may not be sufficiently ambitious for the location with the regional maximum value and may be too ambitious for other locations in the region. In addition, if ocean conditions in all locations within a region are nowhere near the ideal conditions that a functional relationship would reveal, a target based on a spatial comparison may be neither ambitious nor appropriate. Indeed, this possibility causes spatial comparisons to be particularly susceptible to shifting baselines (Pauly 1995).

There will be goals for which a similarly compelling case can be made for using a time series approach versus a spatial comparison. Because they rely on data for a single location at multiple times or for many places during a single snapshot in time, and such information will often be contained within a single data set, time series approaches and spatial comparisons can be used to create specific, measurable, realistic, and time-bound targets. Ultimately, the final choice may depend on whether the assessment process is more interested in tracking a location's performance over time or in comparing assessment units (locations) to one another.

Scaling status

Targets provide the means to express a desired state quantitatively, but they do not prescribe how the current state should be scored as its distance from the target state increases. Ideally this relationship will be linear such that incremental increases in the indicator score convey equivalent increases in status (relative to the goal); a linear relationship eases both interpretation and assessment. Often one does not know the nature of the relationship, making the assumption of linearity the simplest possibility. However, several of the examples described above (see Fig. 1A) suggest that the underlying relationship can be nonlinear.

For nonlinear relationships, it may be possible to infer the shape of the relationship and approximate it through a curve with known properties. For example, if one can reasonably assume that ocean state declines exponentially with increases in associated pressures, then log-transformation of the raw functional relationship provides a convenient technique for rescaling the distance of the current state from the target state. This procedure will produce linear changes in the transformed ocean state as it declines away from the target, thereby accurately representing the nonlinear change in the system.

Scaling status scores in the absence of functional relationships is a more challenging and subjective exercise. It may be necessary to define a range of values considered synonymous with goal achievement. For example, in evaluating recreational water quality in a place not subject to U.S. EPA guidelines, a decision must be reached about the pathogen concentration representing 'clean.' This value need not, and likely will not, be zero. Once the reference point is set, any place where the pathogen concentration is below the reference point can be considered to have met the target, regardless of how far below. In addition, a decision may need to be made regarding the indicator value that constitutes the lowest possible score (i.e., no part of the goal was satisfied). In the recreational water quality example, a judgment call may be necessary to assign the pathogen concentration that represents the extreme of the pollution spectrum, beyond which additional pathogens do not degrade the status assessment further. This decision can be guided by an understanding of societal preferences, among other considerations.

Applying the Framework to Ocean Health and Ecosystem Services

Here we apply our framework to empirical data related to ocean management goals in U.S. coastal systems. We focus specifically on how: the framing of management goals can influence status assessment; qualitative changes in the assessment of ocean conditions may arise from implementing alternative types of targets for the same management goal; and functional relationships can be used to scale the distance of current ocean conditions from target ocean conditions. The examples involve three different management goals—marine livelihoods, fisheries, and water quality—in order to demonstrate the flexibility of the framework for different coupled human-natural systems issues germane to ocean health and ecosystem services.

Goal framing and the evaluation of current ocean state: marine livelihoods

The selection of an appropriate indicator for a management goal can have a dramatic effect on the appraisal of ocean state. We illustrate this point by considering management goals that focus on socioeconomic conditions in coastal areas of the U.S.

Consider a hypothetical goal related to management of a coupled human-natural marine system, such as 'sustaining marine livelihoods.' In principle, this goal can be assessed with a number of different indicators, including employment opportunities, job quality (i.e., economic income), and job satisfaction. We examined how the choice of an indicator(s) can influence the evaluation of the current state of marine livelihoods goals for U.S. coastal states by drawing on data from the National Ocean Economics Program (NOEP 2011). We extracted data from the NOEP market database for the ocean economy by state (including all marine coastal states in the U.S.) for all ocean sectors combined (construction, living resources, minerals, ship and boat building, tourism and recreation, and transportation) for employment (numbers of jobs) and wages (total annual wages; converted to 2000 USD). Average per capita wages were calculated by dividing total wages by number of jobs. We examined the period from 1990 to 1995 because the national employment rate in the United States was relatively constant over this period, eliminating the need to correct for broader economic fluctuations (i.e., according to global unemployment data, the rate of unemployment as a percentage of the labor force was 5.6% in the U.S. in 1990 and 1995; http://data.worldbank.org/indicator/SL.UEM.TOTL.ZS).

We applied a target that captures a desire for stable coastal livelihoods over time using a moving window time series approach. For this example we assumed that a moving window of 5 years is a reasonable reference period, with 1995 as the current year and 1990–1994 as the reference period. In order to represent the spatial variability in scores for each indicator i_t, we reported the exact ratio $i_{1995}/\bar{i}_{1990-1994}$ without bounding the maximum score at one. In effect, this approach encourages economic growth in order to achieve higher scores (in contrast with a no net loss goal). We compared status values from examining a single component of livelihoods (either job quantity or job quality, measured as number of people employed and average per capita wages, respectively) to those that consider both of these dimensions (i.e., by averaging the two).

The status of marine livelihoods across the U.S. in 1995 depended on which of the three indicators was used, and the indicator that provided a higher status score was not consistent across states (Fig. 2). The number of jobs and average wages were positively but not significantly correlated with one another ($r_s = 0.16$; $p = 0.45$; $n = 23$ states; AK and HI included but not pictured in Fig. 2) and most states scored higher for jobs (Fig. 2A), with only two scoring higher for wages (Fig. 2B; MS, MA). A livelihoods status score based on the average of scores for jobs and wages (Fig. 2C) creates an impression intermediate to that based on either indicator individually, and makes the assumption that the two components are equally important (although a weighted average could be calculated to reflect different relative importance). Using both indicators provides a more complex assessment of livelihoods, taking into account that people care both about stable job opportunities and income. Clearly, there are pros and cons to using each of these three indicators and the preferred option will depend on the exact statement of the management goal and the needs of the assessment process.

Lastly, one could argue that these targets are not sufficiently ambitious, given the high values observed across coastal states. On average across all coastal states, the indicators suggested that there were slight gains in jobs (national mean = 1.093) and the combined livelihoods measure (mean = 1.023) and only a slight decline in wages (mean = 0.953). High scores are not surprising for a goal that examines status relative to a recent reference period for metrics such as jobs and wages, which do not tend to show very large fluctuations over a 5-year window. However, if the management goal is the maintenance of the status quo, ambitious may not be the most appropriate or important consideration in setting targets. Thus, this example illustrates the idea that adherence to all five SMART principles is not always necessary or appropriate.

Applying different types of targets to assess ocean state: fisheries

Our framework designates functional relationships as the gold standard for setting scientifically-informed targets, but offers time series

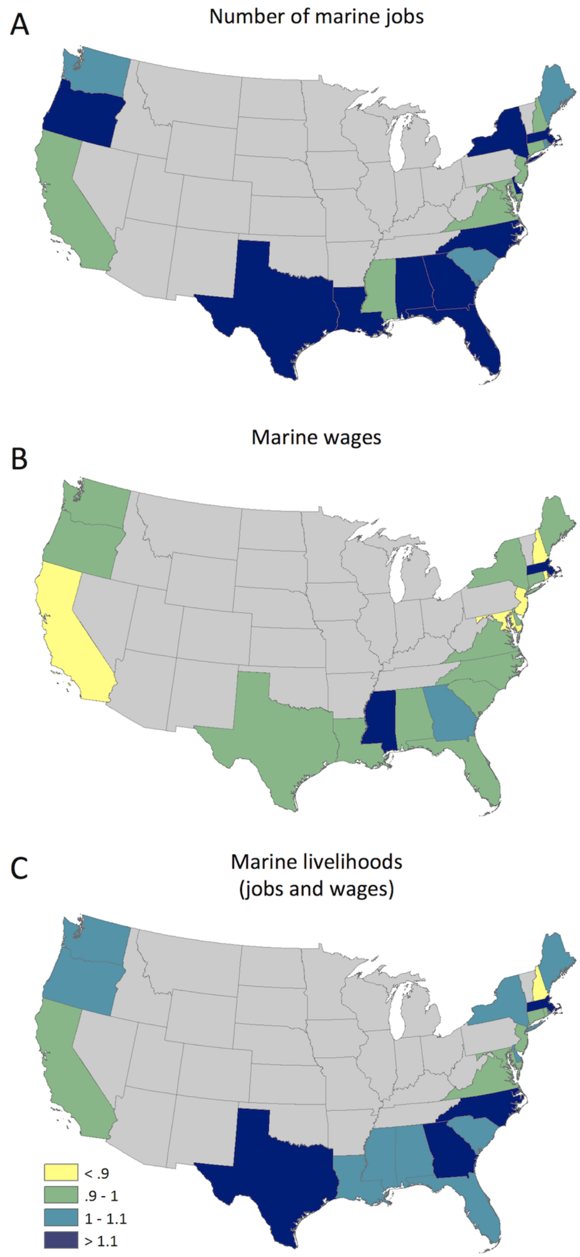

Fig. 2. Status of a hypothetical marine livelihoods management goal for the United States in 1995, using a time series approach to set a target based on a 5 year moving average, calculated using 3 different indicators and currencies: (A) number of jobs, (B) job quality measured via average per capita wages, and (C) an average of the two. Categories represent scores calculated as described in *Goal framing and the evaluation of current ocean state: Marine livelihoods*.

approaches and spatial comparisons as viable alternatives. We recognize that all types of targets, whether intended for this purpose or not, implicitly convey information about absolute state (ocean state now compared to its ideal state) and relative state (ocean state now, in a location of interest, compared to a previous time period or compared to other locations). Even though we consider such comparisons more legitimate when current ocean state at a site is measured against an internal standard based on a functional relationship, it is expected that they will be made regardless of how the target is derived. Indeed, data availability and scientific understanding will often constrain the decision about which type of target to set, so it is important to consider the potential consequences of such de facto decisions.

We explored this idea through the management goal of achieving sustainable fisheries. Fisheries are relatively well understood mechanistically and often have rich data. This quantitative grounding makes it possible to measure the current state of fisheries relative to targets derived using all three of the approaches described in our framework. For the purpose of illustration, we focus specifically on two species of groundfishes important to both commercial and recreational fisheries in the continental United Sates. We chose cabezon (*Scorpaenichthys marmoratus*) and yellowtail flounder (*Limanda ferruginea*) because they are two of the few groundfish for which multiple populations are assessed. This feature allowed us to compare the status of cabezon sub-stocks in Oregon, Northern California, and Southern California and the status of yellowtail flounder stocks in Cape Cod-Gulf of Maine, Georges Bank, and Southern New England-MidAtlantic regions.

We determined targets for the 3 populations of each species by extracting information about total commercial and recreational catch C (units = mt) contained in the most recent stock assessments (NEFSC 2008, Cope and Key 2009). To set the target based on a functional relationship, we relied on an MSY proxy, i.e., the yield expected with spawner potential ratio values corresponding to a spawning stock biomass equal to 40% of unfished levels. In particular, the target (C_{FR}) was set as 91% of the MSY proxy in keeping with the recommendations of Froese et al. (2011). We chose the year of peak catch for each sub-stock as the baseline target using the time series approach, C_{TS} (time series extent for cabezon in California: 1916–2008; cabezon in Oregon: 1973–2008; yellowtail flounder: 1935–2007). Such evaluations are common when catch data, but not estimates of stock biomass, are available (Srinivasan et al. 2010). Finally, to set the spatial comparison target, we determined the area-adjusted maximum catch reported in 2008 (cabezon) or 2007 (yellowtail flounder) for each sub-stock. For cabezon, sub-stock areas were estimated based on the area of suitable habitat in each of the three sub-stock regions (http://www.pcouncil.org/groundfish/fishery-management-plan/fmp-appendices/: Appendix B-4), while for yellowtail flounder stock areas were based on statistical areas used by the New England Fishery Management Council. The spatial maxima corresponded to catch of the Oregon and Georges Bank populations for cabezon and yellowtail flounder, respectively, and we refer to them as C_{SC}.

For each population, our evaluations of status are based on a comparison of the combined recreational and commercial catch in 2008 (cabezon) or 2007 (yellowtail flounder) to the targets described above. We calculated the status S of each population, constrained to the range [0, 1], as follows:

$$S_{FR} = 1 - \frac{|C_{FR} - C_{current}|}{C_{FR}}, \quad (1)$$

$$S_{TS} = 1 - \frac{|C_{TS} - C_{current}|}{C_{TS}}, \quad (2)$$

$$S_{SC} = \frac{C_{current}}{C_{SC}}. \quad (3)$$

Note that for the spatial comparison status calculation we first corrected $C_{current}$ for population area as described above for C_{SC}. Because $C_{current}$ did not exceed target levels for any population using any of the three methods, the current status S can be interpreted as a percentage of the target status.

The cabezon and yellowtail flounder examples provide insight into how impressions of current ocean conditions can change dramatically when different types of targets are applied in assessments. Cabezon status declined from north to south, and the relative status, or rank order, of each sub-stock did not change regardless of which of the three target types was applied (Fig. 3A). However, yellowtail flounder provide a useful contrast (Fig. 3B), suggesting that a consistent rank-ordering of status should not be construed as a general finding from our framework. The assessments based on functional relationship and time series targets agreed that yellowtail flounder status was highest in Cape Cod-Gulf of Maine, intermediate in Georges Bank, and lowest in Southern New England-MidAtlantic. However, the assessment based on a spatial comparison target indicated that the Georges Bank stock status was best, followed by Cape Cod-Gulf of Maine, and finally Southern New England-MidAtlantic. Thus, rank order status of different places can change substantially depending on the type of target that is applied in assessments of ocean conditions.

In addition, the absolute state of the populations differed markedly depending on whether we applied C_{FR}, C_{TS}, or C_{SC} (Fig. 3), providing perspective on how the type of target selected can strongly influence impressions about how close a place is to meeting its management goals for ocean health and ecosystem services. The functional relationship and spatial comparison targets produced roughly similar average status scores for cabezon sub-stocks (0.61 and 0.57, respectively), followed by the baseline target in a distant third (0.34). In contrast, for yellowtail flounder the average score based on the spatial comparison target (0.47) was nearly double that based on the functional relationship (0.20) and eight-fold greater than that based on the baseline target (0.06). Thus, for both species, baseline targets produced a considerably poorer assessment of status than did targets based on functional relationships and spatial comparisons, suggesting that the peak catch levels from which the baseline targets were derived provide an overly optimistic view of sustainable catch levels. While in many applications few options for targets may exist given data availability, it is important to remain cognizant of the caveats associated with interpreting status scores developed from different types of targets and to provide some sense of whether the target type that is selected is considered conservative or non-conservative with respect to absolute ocean conditions.

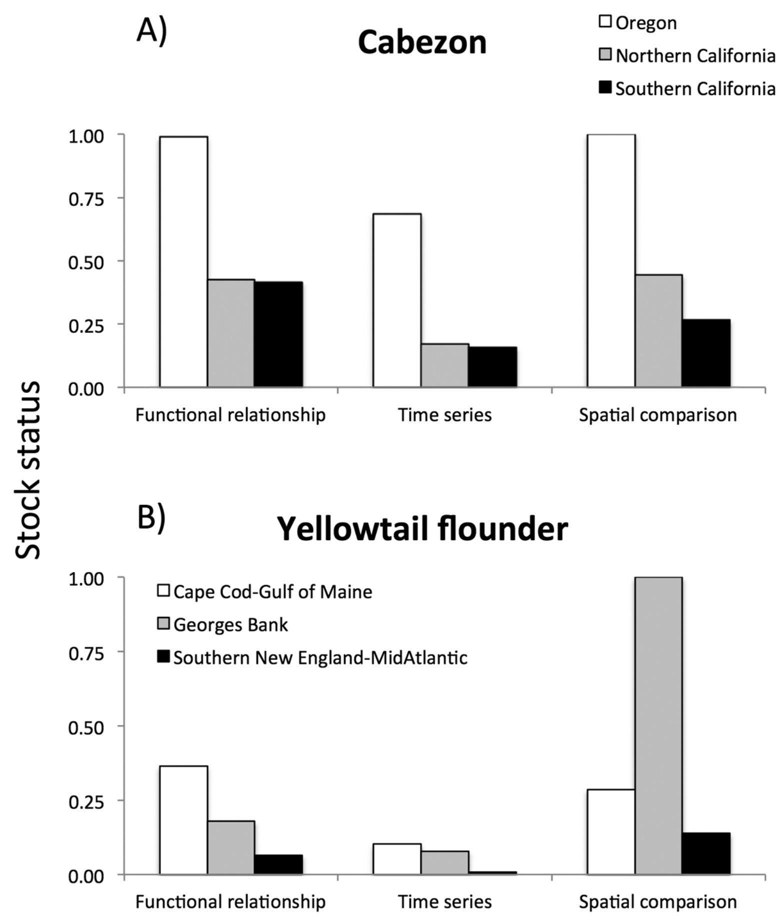

Fig. 3. Comparison of the status of (A) cabezon and (B) yellowtail flounder sub-stocks in the continental United States using targets derived from a functional relationship between yield and fishing effort, a time series approach based on comparison of current and historical yields, and a spatial comparison between the 3 locations for each stock. Cabezon data are from Cope and Key (2009), yellowtail flounder data are from NEFSC (2008), and scores were calculated using Eqs. 1–3.

Scaling proximity of the current ocean state to the target: water quality

We examined a water quality goal to illustrate how functional relationships can be used to scale the distance of current ocean conditions from designated targets. Specifically, we focused on the relationship between nutrient inputs and harmful algae in the northern Gulf of Mexico. Heisler et al. (2008) documented the relative abundance of the diatom genus *Pseudo-nitzschia* spp. in relation to nitrate loading from the Mississippi River (see Turner and Rabalais (1991) and Parsons et al. (2002) for original data sources). Some species of *Pseudo-nitzschia* produce a neurotoxin (domoic acid) known to adversely affect humans and wildlife. A general increase in *Pseudo-nitzschia* since 1950 has been inferred and linked to increased nitrogen inputs related to land use practices (Turner and Rabalais 1991).

The relative abundance of *Pseudo-nitzschia* increased with nitrate loading level to a saturation level within the range of available observations (Fig. 4). To provide an empirical evaluation of this functional relationship, we fit a Generalized Additive Model (GAM) to these data (Hastie and Tibshirani 1990). GAMs represent the relationship between a response variable and one or more independent variables using generalized smoothing functions rather than specific functional forms, allowing substantial freedom in

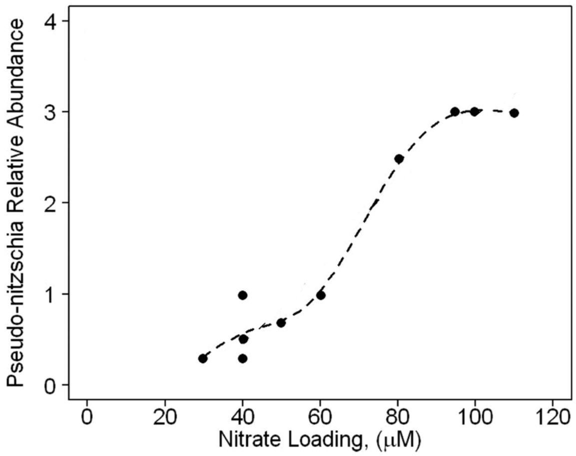

Fig. 4. Fitted relationship (see equation 4) between the diatom *Pseudo-nitzschia* spp. and nitrate loadings in the northern Gulf of Mexico using a Generalized Additive Model. The inflection point occurs at ~67 μM.

defining nonlinear relationships. Our characterization of this relationship using a generalized nonparametric form was based on the generalized additive model structure:

$$g(E[P|N]) = s_o + s_1 N \quad (4)$$

where E is the expectation operator and the s_i are smoothing operators. To determine the change point for this empirical model, we estimated the rate of change between successive observation points in the series and identified the point where the numerically determined second derivative was zero. This analysis indicated a change point at a nitrogen concentration of 67.2 μM.

This information could be used to rescale the score of a management goal that aimed to eliminate sources of pollution that cause harmful algal blooms (HABs). One would presumably give little credit for reductions in N above ~95 μM as they are not expected to reduce HAB frequency; provide a rapid increase in indicator scores for decreases in N to the inflection point at ~67 μM; and, provide a slower increase in indicator scores from there until the desired target reference point (if less than ~67 μM). One simple way to achieve this scaling would be to compare the relative change in *Pseudo-nitzschia* abundance with each incremental change in N and rescale the indicator score between the threshold values above accordingly.

Conclusion

The framework we have introduced in this paper provides a template for how to evaluate ocean health and ecosystem services transparently and systematically. We recommend setting scientifically-informed targets and measuring current conditions relative to them, but doing so within the constraints of what is well-understood scientifically and feasible given the realities of data availability. Compared to outcomes negotiated based on stakeholder opinions alone, science provides a transparent basis for explaining why particular targets were selected, increasing the probability that they will be used in decision making (Gleason et al. 2010). Our application of the framework to several examples demonstrates that it can meet the growing need to conduct assessments for the broad swath of management goals in coupled human-natural systems, while ensuring compatibility and comparability. In fact, the examples presented here suggest this framework may be used as guidance in a variety of assessment types, regardless of whether they are focused on ecosystem benefits in coupled human-natural systems or on biophysical systems considered independently of people.

Selecting the right type of target is a crucial decision because targets set the bar for the achievement of management goals. The appropriate type of target should be faithful to the intent of the goal, meaning it should convey information in the appropriate currency (biophysical, social, or economic units; Tallis et al. 2012). Science cannot provide answers to the value-laden question of what goals for a healthy ocean should be, but given such goal statements it can clarify how to measure progress toward them. In choosing from the three categories of targets we introduced, functional relationships are preferred, scientific understanding and data permitting.

The advantages and disadvantages to selecting different types of targets warrant consideration when making inferences about ocean health and ecosystem services in different places and in relation to multiple management goals. As we observed with the fisheries examples, targets based on functional relationships, time series approaches, and spatial comparisons can lead to very different conclusions about absolute status. Depending on the circumstances, one type of target may set a higher bar than the others. Furthermore, caution is needed when comparing ocean health and ecosystem services for management goals that are common to multiple places, while relying on different types of targets in each place. For instance, it can be inappropriate to compare fisheries status pegged against a target derived from functional relationships in one place and a target derived from time series approaches in another place. When different types of targets must be used, every effort should be made to provide interpretive guidance regarding its reliability and the degree to which it is considered (non-) conservative.

The concepts of ocean health and ecosystem services reflect an emerging desire to capture and evaluate the great diversity of management goals people have for the marine environment under the umbrella of EBM. Realistically, trade-offs among different aspects of ocean health and ecosystem services may prevent achievement of a full suite of EBM targets set one goal at-a-time. Ideally, science could inform these trade-offs by developing functional relationships that describe the simultaneous responses of multiple goals to changes in natural or human-driven variation in environmental conditions. Such information would allow a revision of targets for individual management goals, so that the revised targets would be confined to the realm of the ecologically possible (given trade-offs) rather than that of the desired, but potentially impossible, system state (Samhouri et al. 2011). However, our understanding of the complex interactions between the huge variety of management goals related to ocean health and ecosystem services is embryonic.

In order to move forward now with holistic ocean assessment and management targets, at least two avenues hold promise. One approach is to solicit input from society about desired ocean conditions for goals considered collectively, given compatible and ecologically possible sets of target reference points (Samhouri et al. 2011). Without knowledge of these societal preferences, another approach is to set targets that are ambitious for each goal individually. This method will cause trade-offs to emerge organically within a portfolio of management goals, such that the status of some goals will surpass that of others due to implicit interactions among them. The litmus test for whether the framework we offer has utility will come not just from seeing its implementation in local, regional, and global marine environments, but from observing whether it enables ocean managers and policymakers to improve the flow of benefits to the diversity of people and societies that rely upon the ocean.

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