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Estimating the economic benefits and costs of highly-protected marine protected areas

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Abstract. Marine protected areas (MPAs) are an increasingly popular, but debated, management strategy to conserve marine biodiversity and ensure sustainable human use of the oceans. Economic studies can contribute to the debate about MPAs as a management option by evaluating their benefits and costs to society. In this paper, we outline how to evaluate the economic benefits and costs of MPAs and provide examples from the literature to demonstrate the methods described. We review challenges and opportunities of different economic methods. One key challenge is to meaningfully compare market and non-market benefits of MPAs—this comparison is complicated by the scarcity of studies that quantify the non-market benefits of MPAs. Another key challenge is to quantify how the value of marine areas may change with and without MPAs. Costs are often easier to estimate than benefits, but some costs—such as maintenance and compliance costs—are rarely recognized. Analytical choices will influence the identified economic costs and benefits of MPAs. For example, the spatial extent of analyses will influence what changes in underlying ecological processes are captured and conclusions about the equitable distribution of costs and benefits across society. For these reasons, it is important that managers are aware of the challenges and opportunities described here, so that they can obtain and use the best-quality economic information to guide decision making about MPAs.

Key words: compliance costs; decision making; establishment costs; maintenance costs; market benefits; non-market benefits; with-vs.-without.

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Introduction

There are a number of international initiatives and conventions aimed at increasing the use of marine protected areas (MPAs) for conservation purposes; for example, the Convention on Biological Diversity (CBD 2010) aims to have 10% of the ocean protected by 2020. Marine protected areas are used to mitigate or lessen impacts on ecosystems due to anthropogenic stressors such as habitat degradation (Mora et al. 2011) and climate change (Bates et al. 2014, Roberts et al. 2017). In conjunction with fisheries management, MPAs can also contribute to sustainable use of the oceans, increasing long-term production of fisheries (FAO Fisheries and Aquaculture Department 2012). Well-managed, well-located highly-protected MPAs can generate a suite of ecological benefits by reducing extractive pressure in marine populations and providing increased habitat protection and ecosystem resilience (Bates et al. 2014, Costello 2014). At a time when industrialization is transforming seascapes globally (McCauley et al. 2015), the role of MPAs as reference sites in which ecosystem responses can be measured and contrasted to unprotected areas is increasingly important.

Ecological benefits within MPAs can include increased diversity, abundance, size, and biomass of species (e.g., fish and crustaceans), which can be 2–5 times higher in MPAs compared to fished areas (McClanahan 1994, Russ and Alcala 2004, Lester et al. 2009). Marine protected areas can also provide improvements to ecosystem health (Costello 2014). These patterns hold globally (Lester et al. 2009, Edgar et al. 2014) and regionally (Barrett et al. 2007, McCook et al. 2010). More generally, MPAs may help marine ecosystems adapt to climate change impacts (Roberts et al. 2017), including ocean acidification, sea-level rise, storm intensification (Olds et al. 2014), and shifts in species distributions leading to climate invaders (Bates et al. 2014). Marine protected areas can also impose ecological costs, such as concentrating fishing effort outside their borders, or displacing fishing effort from well-managed systems to less well-managed systems—fisheries managed by multiple jurisdictions or fished by multiple nations can be particularly vulnerable to these impacts (Sarmiento 2006, Chan and Pan 2016). The announcement of an MPA has also been shown to increase fishing effort before the MPA is implemented (McDermott et al. 2019). This is due to fishers anticipating the policy change.

Ecological benefits can translate into economic benefits, including market and non-market benefits. Market benefits are the economic values for goods or services that are observed through a market transaction. Marine protected area market benefits potentially include increased fisheries profitability, which can arise through increased recruitment of juveniles (Harrison et al. 2012) and the spillover of fish biomass from MPAs into fished areas (Russ et al. 2003). Marine protected areas can also provide market benefits through increased tourism (Basurto et al. 2016), or the provision of ecosystem services (e.g., conserved reef systems can protect coastlines from severe weather). Non-market benefits are the economic values for goods or services that cannot be observed through market transactions, and they include the benefit to people from knowing that a threatened species is protected, or that an ecosystem is in good condition (Davis et al. 2019).

There has been debate about the likely magnitudes of the benefits and costs of MPAs. Some have advocated the need for immediate implementation of these areas to counteract the negative impacts of fishing (Russ and Alcala 2004) and highlighted the numerous benefits that MPAs can provide society (Ballantine 2014). Others have expressed doubts about the ability of MPAs to deliver biological benefits (Smith and Wilen 2003, Fletcher et al. 2015), particularly when compared to conventional tools used for fishery management (Hilborn et al. 2004). Economics can help progress this debate in a number of ways, principally by taking a whole-of-community perspective to the assessment of benefits and costs, and by rigorously quantifying gains and losses to different groups within society over time (Ovando et al. 2016). By expressing both benefits and costs in economic terms, ecological importance can be partially translated into a representative monetary value that facilitates decision making by easing comparisons between different benefits and costs (Beaumont et al. 2008).

In this review, our aim is to outline the key methods, challenges, and opportunities of using economics to contribute to decision making about MPAs. In the process, we discuss a number of methodological options and consider the relevance and potential benefits from using economic information. We have focused our discussion on highly-protected MPAs as these have documented ecological benefits across a range of taxa (Edgar et al. 2014), ecosystems (Bates et al. 2014), and fisheries (Hastings et al. 2017). First, we briefly summarize how the benefits that MPAs may provide can be estimated in economic terms, and the challenges involved in obtaining these estimates (Fig. 1). Secondly, we discuss the types of costs that are likely to be generated when an MPA is created. We conclude by summarizing the key challenges in assessing the economic costs and benefits of MPAs, identifying potential solutions to those challenges, and suggesting ways to improve future economic analyses.

Ecological Challenges in Estimating the Benefits and Costs of Marine Protected Areas

There are a number of ecological challenges in estimating the benefits and costs of MPAs. The ecological benefits of MPAs are most simply measured as quantitative changes in characteristics of the ecological community. However, there has been a focus on measuring the ecological impacts of MPAs on commercially exploited species (e.g., fish and invertebrates) as the most obvious targets of extractive activities. Field surveys are used to empirically quantify changes in diversity, abundance, mean size, and biomass of target species through time (before and after protection), or through space (protected vs. fished areas; Lester et al. 2009). The distribution of biomass across functional trophic groups (e.g., predators, omnivores, and herbivores) and size classes has also been quantified (Newman et al. 2006) as fisheries activities have typically removed apex predatory species and larger individuals from the ecosystem first, altering the size distribution of a population (Pauly et al. 1998, Essington et al. 2006). A number of studies have also used modeling to anticipate the effects of MPAs, both in terms of fisheries displacement (Halpern et al. 2004) and increases in target species recruitment (Polacheck

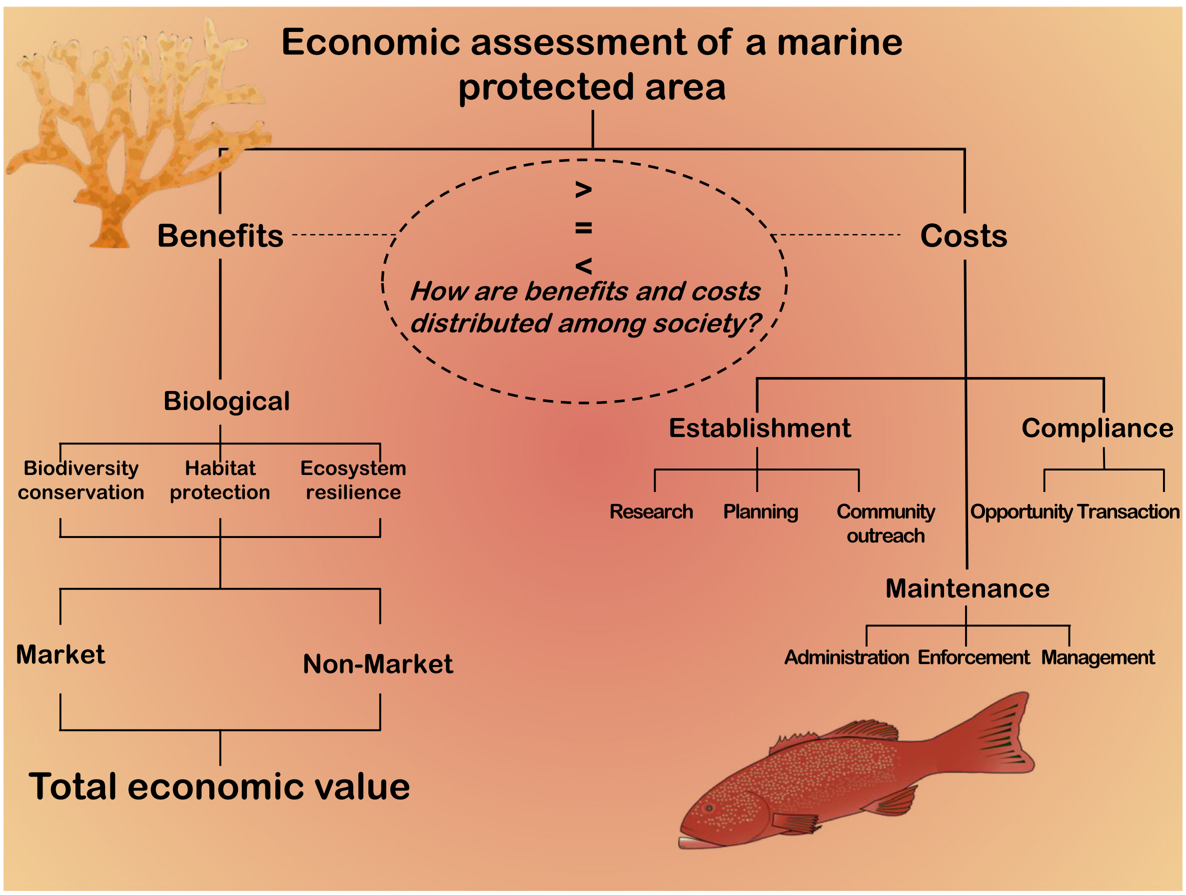

Fig. 1. Components of a comprehensive economic assessment of a marine protected area, including major benefits and costs that need to be considered. Economic analysis can help determine whether benefits are greater than, or less than costs, and how benefits and costs are distributed across society. Image credits: branching coral, D Kleine, Marine Botany UQ; Coral trout, K Kraeer, L V Essen-Fishman–Integration and Application Network, University of Maryland Center for Environmental Science (ian.umces.edu/imagelibrary).

1990, Harrison et al. 2012). In what follows, we briefly review key ecological challenges that must be overcome in any rigorous assessment of MPAs —not just when assessing economic costs and benefits.

Challenge 1: With-vs.-without comparisons

A major challenge in any assessment of the impacts of MPAs centers on the ability to identify the with-vs.-without impacts of MPAs (Fig. 2). We assume that the analyst is interested in how the value of an area changes after an MPA is established. Whether value is measured in ecological or economic terms, the analyst must assess the change in value with an MPA (Fig. 2, points 3) relative to the value without an MPA—the latter is termed the counterfactual (Fig. 2, points 2). If an MPA has been implemented, the with-MPA scenario is observable but the without-MPA scenario is unobservable, and hence, relevant values can be difficult to estimate. The analyst must account for the expected trajectory of value over time; for example, this could be constant (Fig. 2A), declining (Fig. 2B, C), or even improving (Fig. 2D). Even if the value of interest declines in the with-MPA scenario (Fig. 2C), benefits of the MPA can be positive if the decrease would have been greater without the MPA. If the MPA is being evaluated prior to its implementation, then both the with- and without-MPA scenarios have to be predicted; see, for example, Sanchirico and Wilen (2001). They are likely to be equally difficult to predict.

Any evaluation of MPA impacts must also satisfy two key assumptions (Ferraro et al. 2019). The first assumption is that changes in value are driven by MPA designation and not due to other market or environmental effects, for example, excludability. In Fig. 2D, the underlying value of a marine area improves without an MPA—this could be due to changes in policy, such as fishery restrictions or buy-backs. The analyst needs to assess the difference with-vs.-without the MPA (points 3 and 2) to capture the true effects of the MPA—not the difference between pre-MPA values (point 1) and values with an MPA (point 3). The excludability assumption could be satisfied by randomizing MPA location among a set of locations where the effects of an MPA would be entirely contained (Ferraro et al. 2019). However, randomization can be difficult in practice as MPAs are typically located in areas of ecological importance or where they will minimize adverse impacts on fisheries. Where randomization is not possible, managers can identify and control for rival market or environmental effects (which may drive differences in value) using conditioning strategies, including regression or matching estimators (Ferraro and Hanauer 2014). Analyses using panel designs, which exploit repeated observations before and after MPA establishment, can be used to control for unobservable but time-invariant confounders (Ferraro et al. 2019). The second assumption that must be met to assess MPA impacts is no-interference; for example, outcomes in a given marine area are not influenced by whether another area was designated as an MPA. There are several options to address interference in marine systems, described fully in Ferraro et al. (2019) and summarized briefly below: (1) acknowledge interference exists and limit the MPA effect that is being assessed to one that could only occur with the exact MPA-implementation conditions; (2) use a partial identification approach; (3) use experimental or quasi-experimental saturation designs; and (4) change the spatial unit of analysis, for example, by choosing control sites sufficiently far away from the MPA.

Challenge 2: Choosing appropriate control sites

It is very challenging to identify a truly independent control site to serve as a counterfactual as areas inside and outside of MPAs are likely to be subject to MPA effects (Caselle et al. 2015), including dispersal (spillover; Claudet 2017). Furthermore, effort displacement from MPAs may actually displace habitat pressure (i.e., use and extraction) to control sites—confounding the measurement of MPA effects (Halpern et al. 2004). Spatial comparison of locations inside and outside MPAs and examination of long-term trajectories of MPAs relative to unprotected areas (McCook et al. 2010) can provide data to overcome this confounding effect. However, spatial comparisons can be complicated by heterogeneity in habitats both within and between locations (Starr et al. 2015). Such variability means that estimated benefits will be sensitive to local conditions and fishing histories, increasing the number of studies (and thus cost) required to understand the ecological benefits of MPAs.

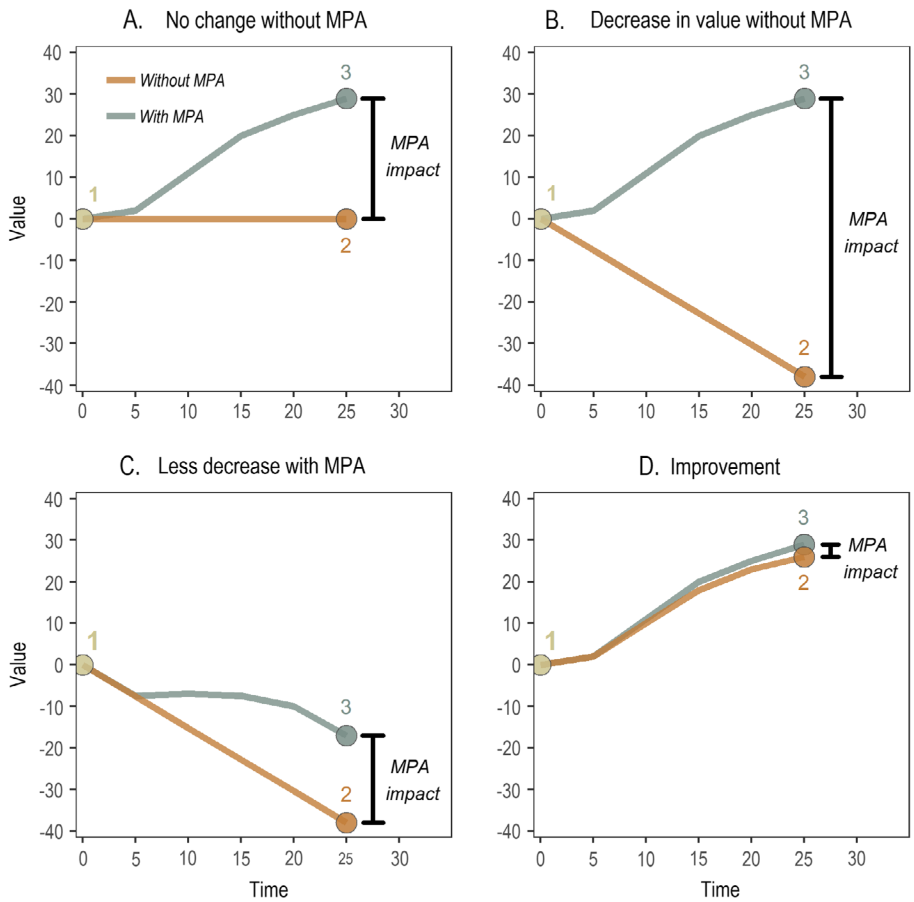

Fig. 2. In a given marine area, the changes (here expressed as a percentage increase or decrease) caused by the introduction of a marine protected area (MPA) need to be measured in relation to the expected value of the area without the MPA. This is equivalent to evaluating the difference between points 3 and 2, not points 3 and 1 (pre-MPA value).

Spatial variability also means that response to protection will vary greatly from local to regional to global scales (Claudet 2017). Sampling at many sites across a gradient of distances from the reserve boundary may be required (Newman et al. 2006). To account for differentiated human impacts in different marine areas, it may also be necessary to quantify pre-protection fishing intensity—this allows the analyst to evaluate whether there were parallel trends at MPA and comparison sites before an MPA was established (Ferraro et al. 2019).

Challenge 3: Management effects

Finally, the management characteristics of MPAs can hide several confounding features: (1) Not all of what is protected under MPAs is fully protected; (2) very large MPAs are being established in remote areas, which may not need protection; and (3) MPAs often do not receive adequate enforcement, compliance, and management (Claudet 2017). Any assessment of the ecological benefits of MPAs will need to control for these management qualities.

The Market Benefits of Marine Protected Areas

There are two principle market benefits (Box 1) of MPAs that have been documented: benefits to fisheries and to tourism. The former is due to increases in the recruitment of juvenile fish

Box 1.

Definitions of key economic concepts

Market benefits. A market benefit relates to some good or service that is bought and sold and therefore is associated with a market price. It is worth remarking that market prices may not truly reflect a good or services' total value; individuals may value items in ways not captured by changes in wages or property values (Hanemann 1994) (Fig. 3). Generally, values identified as direct use (Fig. 3) are those that are most likely to be observed in a market (Hoagland et al. 1995). The existence of a market price makes transparent the existence of a benefit and facilitates its measurement, although measurement challenges remain.

Consumer surplus. Consumer surplus is the difference between the price paid for a good and the highest price that the consumer would have been willing to pay (Fig. 4). The concept has similarities to business profit. In both cases, there is a gain (represented by business revenue or a consumer's maximum willingness to pay) and a cost (the cost of purchasing inputs, or the cost of purchasing the good) and the benefit is calculated as the difference between the two.

Discounting. Discounting reflects the financial reality that income received earlier can be invested for longer in income-earning opportunities, or that costs incurred earlier divert funds from income-earning opportunities. The impact of discounting on the magnitudes of measured benefits can be substantial, especially for benefits in the more distant future. For example, using a real discount rate of 10% (realistic for some businesses), a real benefit of $100 in 20 yr time would be equivalent to $15 in the present.

(Harrison et al. 2012) or movement of adults (Russ et al. 2003) from MPAs into adjacent fisheries and/or increase in the size of individuals, resulting in increased commercial catch (Roberts and Sargant 2002), particularly for older MPAs with high enforcement (Ban et al. 2017). Whether MPAs provide benefits to fisheries will depend on a range of features, including (1) source–sink dynamics of the fish population, (2) size of an MPA relative to the home range of fish species (Ovando et al. 2016), (3) geographic extent of the fish population, (4) status of the fishery prior to MPA implementation (Ovando et al. 2016), and most importantly, (5) adequate management and enforcement. Where sustainable catch rates differ across species, leading to strong and weak stocks, MPAs may also benefit fisheries by reducing the cost of bycatch reduction (Hastings et al. 2017). Generally, economic benefits to fisheries are experienced as increased revenue per unit of fishing effort, or reduced effort and cost per unit of fish caught. Marine protected areas can also increase income opportunities outside of fishing (Basurto et al. 2016), in particular, by increasing tourism revenues (Sala et al. 2013, Vianna et al. 2018). Examples include MPAs in New Zealand (Costello 2014), the Philippines (Arin and Kramer 2002), and Gulf of California, Mexico (Wielgus et al. 2008). Benefits may include income to tourism operators and spin-off benefits to other local businesses (e.g., restaurants and hotels) through increased custom from tourists (Vianna et al. 2012).

Marine protected areas may provide other indirect market benefits (Fig. 3) that stem from ecosystem services. For example, enhanced ecosystem resilience in MPAs may help mitigate coastal damage from extreme weather events or coastal erosion (Angulo-Valdés and Hatcher 2010). This could decrease public or private expenditure on responses to natural disasters or on coastal infrastructure. Marine protected areas may also provide increased resilience against climate invaders that can have damaging impacts on fisheries catch (Bates et al. 2014). Additionally, MPAs provide the opportunity to increase knowledge of marine ecosystems. This increased knowledge can help marine managers design MPAs that are less expensive to establish and maintain, and more effective at protecting marine biodiversity. Increased ecosystem resilience and increased knowledge of marine ecosystems are not goods that are directly traded in a market; however, their economic value can be quantified relatively easily through observing related market transactions (e.g., hedonic approaches; de Groot et al. 2012).

Quantifying the market benefits of marine protected areas

Direct market benefits attributed to MPAs may flow to at least three groups of beneficiaries: businesses (primarily those related to fishing and tourism), consumers who purchase products and

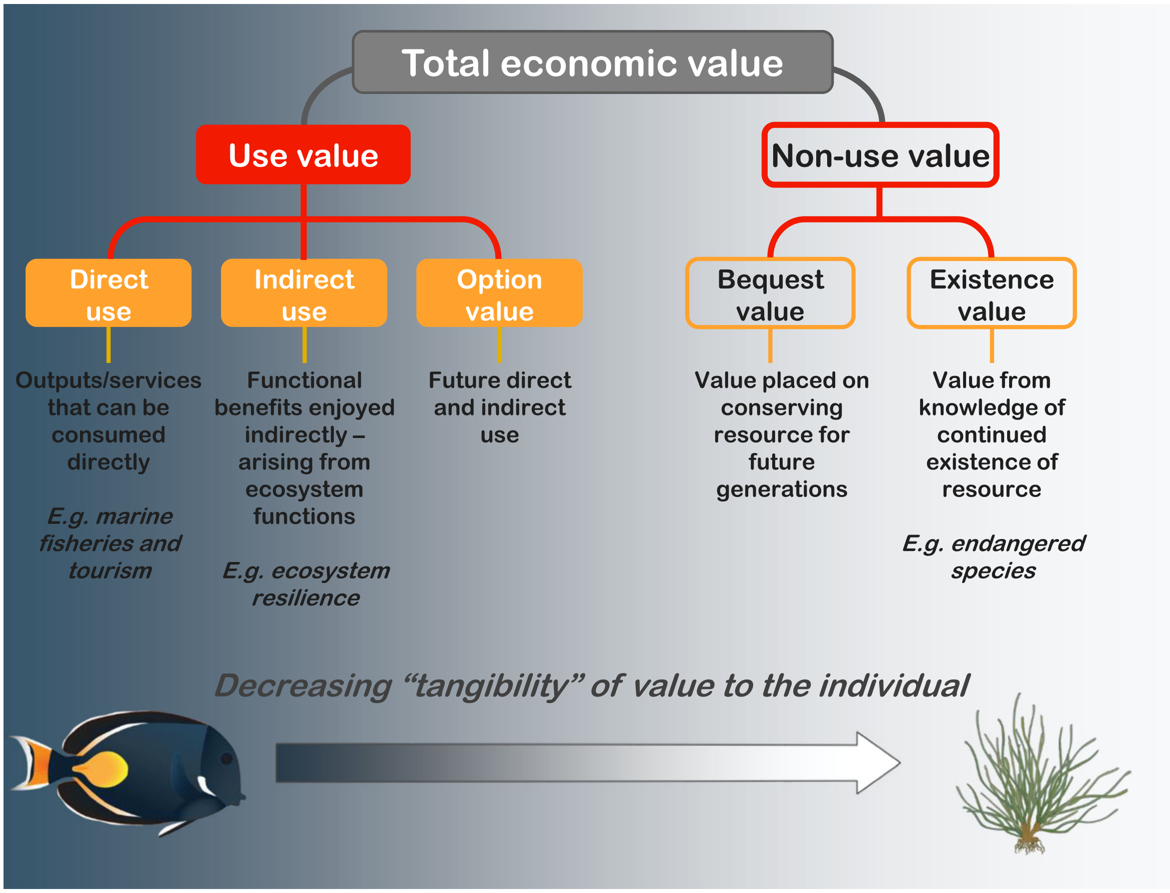

Fig. 3. Total economic value of a marine protected area. Image credits: Achilles Tang, J Woerner; Zostera caespitose, T Saxby–Integration and Application Network, University of Maryland Center for Environmental Science (ian.umces.edu/imagelibrary).

services that depend to some extent on MPAs, and the local community (often represented by government) who can benefit from the generation of jobs and the payment of additional fees and taxes where these are paid by international tourists.

Similar to ecological benefits, market benefits for businesses are approximated by the difference in profits of a business with-vs.-without the MPA. This difference in profits can be calculated and compared with the costs of providing an MPA. Non-biological factors that affect fisheries benefits from an MPA include (1) the sale price of fish whose catch level changes, including the way those prices change over time or for larger fish; (2) the change in sale price if the supply of fish increases (due to the downward slope of the demand curve); (3) the costs of fishing effort, including the way those costs change over time, for example, in response to changes in harvest technology (Ferraro et al. 2019); (4) the scale of the exploited resource (Burgess et al. 2017); (5) proximity to fishing ports and processing infrastructure; and (6) the nature of regulation, scrutiny, and management imposed by government on the fisheries (Hughes et al. 2016, Burgess et al. 2017, Ferraro et al. 2019). The benefits to tourism operators are also driven by a somewhat similar list: (1) How tourist numbers increase due to increases in marine life abundance; (2) the market price of tourism services, and the way this changes in response to the establishment of the MPA (the demand curve); (3) the costs of providing tourism services; and (4) the constraints imposed by government.

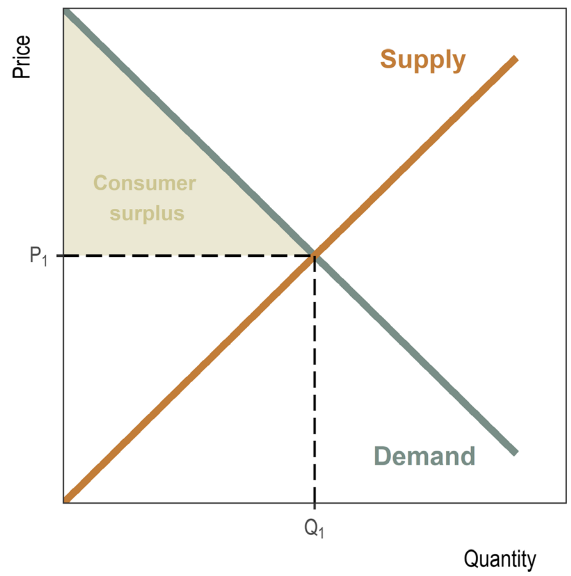

Fig. 4. Example supply and demand curves for marine resources provided by marine protected areas. Consumer surplus (shaded off-white) is bounded by the demand curve and the intersection of Q_1 and P_1.

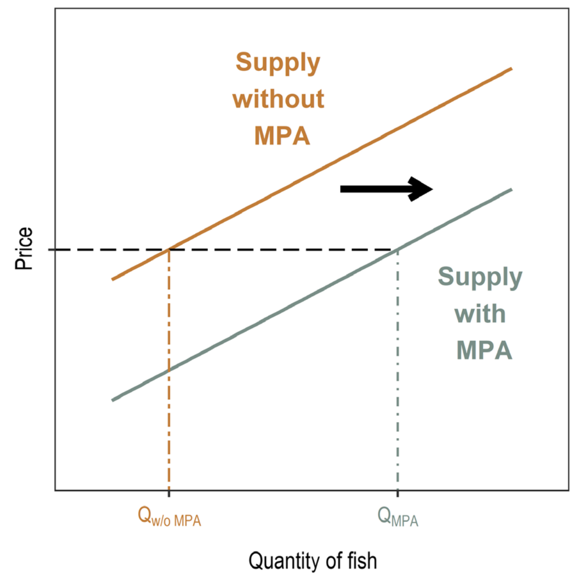

Fig. 5. Introducing a marine protected area (MPA) may lead to increases in commercial catch (aka the quantity of fish supplied) through increased recruitment of juvenile fish, movement of adults from MPAs into adjacent fisheries, and increases in the size of individuals. This causes the supply curve for fish to shift to the right.

Consumers benefit from MPAs if they are able to purchase products (e.g., fish for consumption) and services (e.g., tourism experiences) that they prefer to the products and services that they would otherwise have purchased with the same money, or are able to purchase similar goods at a lower price. Economists usually measure these benefits as changes in consumer surplus (Box 1).

A key piece of information required to estimate consumer surplus is the demand curve for the particular product or service. This specifies the relationship between the price of the good and the quantity that consumers will choose to purchase (or conversely the marginal willingness to pay for different quantities of the good). There is a large literature on the statistical estimation of these curves under different circumstances (Deaton and Muellbauer 1980, Brasington and Hite 2005, Burgess et al. 2017). Specialized statistical techniques are required to account for the fact that prices are determined by the interplay of supply and demand. Demand curves are used to estimate the change in consumer surplus following a change in supply (e.g., of fish for consumption) due to the MPA (see, for example, Figs. 4, 5). An increase in supply would not only increase consumption, it could also lower the price paid by consumers, giving them an additional benefit.

To quantify the market benefits of MPAs for the community, any increase in public revenues or decrease in public costs needs to be measured relative to an appropriate counterfactual—what would have happened without the MPA (Fig. 2). Once again, this analysis must meet excludability and no-interference assumptions: Changes in these benefits are wholly due to the establishment of an MPA and not affected by how contiguous areas are managed. This also requires that revenue and cost information have been recorded by the relevant government department to allow their quantification and assessment.

All three benefit categories (business, consumer, and community) need to be aggregated over time, recognizing that the same level of profit generated at different points in time has a different value. For benefits to be aggregated validly, an analyst must account for two factors: inflation and the opportunity cost of capital. With inflation factored out of a stream of benefits, they are said to be expressed in real terms, reflecting real purchasing power at different points in time. In addition, expressing future real values in terms of their present value requires discounting (Box 1; Pannell and Schilizzi 2006). Discounting can have a significant impact on the measured market benefits of MPAs because it can take between 1 and more than 20 yr for biological benefits, and hence market benefits, to accrue after establishing an MPA (Halpern and Warner 2002, Edgar et al. 2014, Starr et al. 2015). These future benefits need to be discounted to present values before they can be compared with the up-front capital costs of MPA creation, and short-term fishery losses. Recognizing that up-front capital has an opportunity cost increases the challenge of generating sufficient benefits to outweigh the costs of MPAs (Armstrong 2007).

Challenges with estimating market benefits of marine protected areas

Although the observation of market prices eases the estimation of benefits from MPAs to some extent, there remain a number of significant challenges.

Challenge 1: Shifts in the demand curve.—There can be uncertainty regarding the slope of the demand curve, and the shift in the demand curve due to the MPA (Fig. 5). Typically, it is only possible to observe supply and demand within a limited range of quantity supplied. If an MPA pushes quantity outside historic ranges, the slopes of supply and demand curves can only be estimated by extrapolation beyond the observed sample. Even if the MPA is in place, such that demand with the MPA can be observed, demand without the MPA cannot be observed, yet must be estimated. The chain of causal links, from establishment of an MPA to generation of commercial benefits to businesses, both fisheries and tourism operators, is long and complex. This complicates the accurate estimation of market benefits. The most useful approach is likely to be creation of a bioeconomic model that quantifies and links each element in the causal chain, flowing into quantified business revenue and costs for any given scenario (see, for example, Sanchirico and Wilen 2001). This bioeconomic model could then be used to estimate the change in profits with-vs.-without an MPA.

Challenge 2: Analytical tools.—There are various challenges with the analytical tools used to estimate the market benefits of MPAs. For example, the preference of decision makers may be to factor in the benefits to domestic rather than international consumers (e.g., international tourists). However, discriminating between domestic and international consumers who are both participating in the domestic market is not possible using standard economic methods for estimating the demand curve. Note that revealed-preference methods (see next section) can be used to capture these differences for non-market values; see, for example, Ahmed et al. (2007). The complexity of the causal links between the ecological benefits of MPAs and market benefits for businesses necessitates sophisticated models that can capture such second-round effects, for example, Dyck and Sumaila (2010). However, anticipating second-round effects of an economic change adds to analytical difficulty. For example, an increase in tourism would generate additional income for businesses and employees in the tourism sector, but they would then spend some of this additional income on other goods and services. Quantifying these flow-on effects on consumption and prices would require a multi-market model of the whole economy, rather than just a model of demand for particular tourism services. A further risk is double counting benefits. For example, some of the revenue received by a business and its employees is paid to governments as taxes. These amounts should either be included in the estimated benefits to business or the estimated benefits to government, but not both (Fu et al. 2011).

The Non-Market Benefits of Marine Protected Areas

The measurement of the non-market benefits generated by MPAs is more challenging because these benefits relate to goods or services that are not traded in a market and are therefore not associated with a market price. Values identified as indirect and non-use (Fig. 3) are those that are less likely to be observed in markets (Hoagland et al. 1995). However, a number of procedures have been developed to estimate these values and we discuss these below.

Non-market use benefits include non-commercial recreational or tourism activities (Fig. 3), such as diving or snorkeling (Ledoux and Turner

2002)—these benefits may be more prevalent in accessible MPAs. Where MPAs are remote, and hence difficult for people to access or use, non-use values may be more important to consider (Johnston et al. 2012), although non-use values will also exist for accessible MPAs. Non-use MPA benefits include existence and bequest values (Fig. 3), where the former is the benefit people obtain from knowledge of the continued existence of an MPA (Christie et al. 2015), or environmental goods that are protected by an MPA, even when they will never visit the MPA or use its resources (Hoagland et al. 1995, Armstrong et al. 2017). Most existing research on non-use values has focused on charismatic species such as marine mammals and turtles, or prominent ecosystem components such as corals (Börger et al. 2014). Bequest value is the value people place on ensuring that an MPA and the environmental goods it protects are available for future generations (Togridou et al. 2006). The non-market benefits of MPAs are defined in terms of consumer surplus (Box 1 and Fig. 4). However, the absence of prices or market data to infer demand curves makes the identification of consumer surplus more difficult.

Quantifying the non-market benefits of marine protected areas

Non-market values are usually measured by revealed-preference (Viana et al. 2017) and stated-preference (Davis et al. 2019) methods. The former use data on consumers' observable choices to infer values for environmental goods. Revealed-preference methods can only capture values that arise from people using (interacting with) MPAs. A useful valuation method to value the non-market benefits of MPAs is the travel cost method (Brown and Mendelsohn 1984, Pascoe et al. 2014), which relies on information about the costs incurred by people to visit a site. These costs are interpreted as an unobserved shadow price for site visits. The relationship between this shadow price and the quantity, or frequency of visits to the MPA, expresses the shadow demand function for the MPA (Alban et al. 2008). Another revealed-preference technique that may be relevant to MPAs in some cases is hedonic pricing. This interprets marine environmental quality as an attribute of a differentiated market good (Rosen 1974). For example, homes located close to an inshore MPA may command a price premium. This premium can be measured by observing prices paid for homes that are or are not close to an MPA, controlling for all other attributes.

Benefits from MPAs can also be measured using stated-preference methods (Börger et al. 2018, Davis et al. 2019). These methods are based on information from surveys rather than behavior. Stated-preference methods have the advantage that they can elicit use and non-use values, such as the loss of well-being people would feel if, for instance, a species became extinct. Surveys can also assess preferences for how an MPA should be managed (Rogers 2013*b*). The two main stated-preference methods are contingent valuation (CV) and discrete choice experiments (DCEs; Carson and Louviere 2011). In CV, the economic value of a public good is inferred using information related to preferences that is obtained through a survey (Spurgeon 1992, Carson and Louviere 2011). For example, values of US$6 per family visit were estimated using CV in southern California for policies that reduced damage to MPAs through more effective enforcement and management (Hall et al. 2002). In a DCE, respondents are asked to select their preferred choice from several options that vary in their outcomes and in their cost. From their responses, their implicit valuations of the outcomes can be derived statistically (Adamowicz et al. 1998). For example, Wattage et al. (2011) used a DCE to determine the Irish public's economic value for the conservation of deep-sea corals. They found respondents were willing to pay a personal tax of €1–€10 to ban trawling in all known coral areas. In another example, it was estimated that divers visiting a popular destination in Malaysia were willing to pay a fee for establishment and enforcement of a shark sanctuary that would generate over US$2 million per year (Vianna et al. 2018).

Challenges with estimating non-market benefits of marine protected areas

Not all non-market valuation methods can be used to value all MPAs. Revealed-preference methods such as travel cost or hedonic methods are limited to the valuation of goods that affect consumer choices in related markets, such as recreational trips and property purchases (Börger et al. 2014). Some attributes of an MPA, such as those related to the deep sea, lack any direct effect on market activities or values, precluding the use of revealed-preference valuation methods (Börger et al. 2014, Armstrong et al. 2017). Stated-preference methods can be used to estimate these values but may be subject to bias because they are based on hypothetical scenarios and decisions. Hypothetical bias may be reduced by making explicit linkages between the survey and an official government process (Johnston 2006). This bias is also likely to be less prevalent in contexts where the environmental good is familiar or more salient (Johnston 2006). Stated-preference methods also rely on people having an adequate knowledge and understanding of the issues they are being asked about (Chee 2004, Aanesen et al. 2015, Johnston et al. 2017). New information that can be taken in and processed by respondents as part of the survey process is limited (Burton et al. 2015). For some issues, technical expertise may be needed to judge values or importance. One alternative is to rely on experts rather than the general public to provide values, but there is a trade-off here, as past research has shown that values elicited from experts are not necessarily representative of the broader community (Rogers 2013*a*).

Costs of Marine Protected Areas

There are three main costs associated with MPAs: establishment, maintenance, and compliance costs (Fig. 1). Most MPAs are likely to incur similar types of establishment and maintenance costs, although the magnitude of these costs will differ. Compliance costs relate to affected fishers, rather than to the organization that is responsible for an MPA and will be discussed separately. Note that MPAs will also affect social dynamics in a community (Basurto et al. 2016). This can be experienced as increased prosocial or antisocial behavior, caused by changes to catch rates and an increase in income opportunities (e.g., tourism) outside of fishing. Not all sectors of the community will be able to exploit these new opportunities, which can exacerbate social stratification.

Estimating establishment and maintenance costs of marine protected areas

Establishment costs include research and planning costs, as well as those incurred for outreach activities with the local community or other stakeholders (McCrea-Strub et al. 2011). During the establishment of an MPA, costs may also be incurred to perform ecological and socio-economic research, including collection of baseline ecological data, modeling of ecological changes under different climate or management projections, and quantification of social impacts (Agardy 2000). Establishment costs may also include costs for training and infrastructure.

Maintenance costs include administration, management, and enforcement costs. Each of these categories is composed of staff expenses, operational costs, and recurrent capital costs such as purchase and maintenance of vehicles and vessels (Ban et al. 2011). If enforcement is effective, there will likely be legal fees for prosecutions (Ban et al. 2011).

Quantifying establishment and maintenance costs of marine protected areas

Quantification of establishment and maintenance costs is conceptually straightforward. They consist of readily measurable economic costs that, in principle, should be obtainable from the relevant organizations. To our knowledge, McCrea-Strub et al. (2011) are responsible for the only detailed study of establishment costs. The authors used data for 13 MPAs worldwide to derive a model to estimate establishment costs. The study shows that variation in MPA establishment costs is most significantly related to MPA size, and the duration of the establishment phase; greatest cost efficiency is achieved when establishing a large MPA over a short period of time.

A number of studies have made detailed investigations of the factors influencing maintenance costs. Balmford et al. (2004) found that global annual running costs per unit area spanned six orders of magnitude and were higher in MPAs that were smaller, closer to coasts and in high-cost, developed countries (Balmford et al. 2004). Gravestock et al. (2008) concluded that maintenance costs were dominated by MPA size and visitor numbers and to a lesser extent by the purpose of the MPA, dominant habitat type, parent nation wealth, source of funds, and zonation. Although both Balmford et al. (2004) and Gravestock et al. (2008) found that maintenance costs per unit area decreased as MPA size increased, Ban et al. (2011) suggested that this relationship may be non-linear: Economies of scale may initially dominate the relationship between increasing MPA size and management cost until a threshold is reached whereupon costs would again increase as MPA size increased.

Challenges with estimating the establishment and maintenance costs of marine protected areas

Different MPAs are established with different management objectives in mind. This makes it unlikely that costs will be consistent and hence straightforward to predict (Gravestock et al. 2008). Establishment costs depend on the time taken to establish an MPA, but this is difficult to predict and likely to vary substantially between MPAs (McCrea-Strub et al. 2011). Establishment costs are also likely to be spread across various entities, both public and private, further complicating their measurement (McCrea-Strub et al. 2011). Estimation of maintenance costs can be made difficult by the complexity of MPA attributes, including different sizes, locations, demands on resources (e.g., by visitors or for enforcement), and the degree of focus on community relations and education (Gravestock et al. 2008, Ban et al. 2011).

Even where an MPA is already in place, estimation of costs can be difficult due to limitations of institutional memory and economic records and will depend on the willingness of all funding sources to divulge economic data (McCrea-Strub et al. 2011). Where documented, cost information typically exists in the gray literature, which may have limited availability and is not often systematically catalogued (Gravestock et al. 2008). In particular, data on the costs of building local and national capacity and political support for MPAs are limited (Balmford et al. 2004). Such management cost data that do exist are often highly aggregated and may only reflect broad categories (e.g., staff, operation costs) or total costs (Ban et al. 2011) or be combined with other non-MPA costs. The majority of existing MPAs are quite small, and their costs are of limited relevance to larger MPAs, such as those planned for the Coral Sea (Ban et al. 2011). Uptake of cost reporting standards as outlined by Iacona et al. (2018) would increase standardization, and hence access and usability, of MPA costs.

Estimating compliance costs of marine protected areas

Two main types of compliance costs that are relevant to MPAs are opportunity and transaction costs. The former is a benefit that could have been generated but is foregone to pursue some other benefit. In the case of MPAs, fishers face an opportunity cost equal to the loss of profits that results from banning fishing within the MPA. These opportunity costs are primarily borne by private businesses—for example, fishers. Where compensation is offered to offset opportunity costs, the community will also bear a cost. Perceptions of high opportunity costs are behind much of the opposition to MPAs that is expressed in political debates (Smith et al. 2010). Transaction costs are borne by fishers and others in the course of MPA policy administration. Transaction costs include the costs of time spent learning about the MPA and its implications, completing any required paperwork, reporting, holding discussions with program staff, and obtaining legal advice (McCann et al. 2005).

Opportunity costs of marine protected areas: description, measurement, and challenges

Opportunity costs should preferably be measured as reductions in profits, not just reductions in revenues, because input costs may also change (Hughes et al. 2016). Prior to MPA establishment, the opportunity cost would be indicated by the profits then being made by businesses from their activities within the planned or proposed MPA. In some countries, and for some types of businesses, that information may be publicly available, but in other cases, it is private and confidential. Reimer and Haynie (2018) were able to access a confidential dataset of annual fishing revenues and costs, which allowed them to estimate the effect of a large marine reserve on the net earnings of a commercial fishery using difference-in-differences and synthetic-control designs. When considering how opportunity costs may change over coming decades, allowance needs to be made for subsequent changes that would have altered profits in the absence of the MPA (Fig. 2). These changes include changes to fisheries policy, for example, license or effort buy-outs; changes in technologies; and changes in output prices or input costs, for example, fuel costs (Hughes et al. 2016). Fisheries profitability will also be affected by other management, economic, and social changes that have occurred since an MPA was established—an analyst cannot conclude that all catch losses are due to MPA establishment (Hughes et al. 2016). The opportunity cost of creating an MPA depends on the other economic opportunities available to businesses. For example, if the economy is booming outside the fishing industry, fishers would suffer smaller economic losses from leaving the fishing industry and moving into another sector. This highlights that opportunity costs need to be measured relative to the next best income-earning activity available to the affected businesses and workers, which may be either inside or outside the fishing industry. The true opportunity cost will almost always be less than the reduction in fishing profits within the MPA, because fishers can often move to alternative fishing grounds, that is, have spatial mobility (Cinner 2007), or to alternative occupations.

A feature of opportunity costs to fishers is that they occur in the short term, commencing as soon as the MPA is created. On the other hand, any benefits to fishers arising from increased fish abundance outside the MPA are likely to be delayed. The length of the time lag depends on biological factors, principally the dispersal of fish and growth rate of the species impacted by fisheries (Brown et al. 2015). The ability of reserves to provide net present benefits to a fishery depends largely on the state of the fishery (e.g., whether it is overfished), the interplay between the rate at which spillover benefits accrue to the fishery and the rate at which the value of those future benefits decays due to the discount rate (Ovando et al. 2016). Discounting future benefits, to allow for the opportunity cost of capital (Box 1), makes it less likely that benefits will outweigh short-term opportunity costs (Smith et al. 2010). For example, Ovando et al. (2016) found that MPAs, irrespective of size, would only generate benefits for fisheries if discount rates were below 15–30%; this is problematic given that fishers often have high discount rates (Brown et al. 2015). To overcome this challenge, Ovando et al. (2016) propose a metric to evaluate the impacts of MPAs on fisheries, which they describe as net present balance. This metric describes changes in yield over time relative to the status quo and is a function of both the stream of future yields relative to the status quo and the discount rate. The choice of discount rate can be informed by published government guidelines, for example, H.M. Treasury (2018).

The presence of subsidies to fishers can complicate estimation of opportunity costs in some countries (Tyedmers et al. 2005, Sumaila et al. 2010). Subsidies mean that fishers' profits no longer reflect true opportunity costs from a whole-of-society perspective and that fish catch may exceed the socially optimal level. In principle, a benefit cost analysis of an MPA proposal should estimate opportunity costs based on estimates of profits and fishing activity in the absence of subsidies. Of course, subsidies remain relevant to the consideration of winners and losers from the proposed policy change.

Transaction costs of marine protected areas: description, measurement, and challenges

Although recognition of, and interest in, transaction costs in natural resource programs and policies has increased in recent years (McCann 2013, Pannell et al. 2013, Loch and Gregg 2018), there are still relatively few studies that have measured these costs. To do so is challenging, as it requires detailed information about time taken by businesses to undertake MPA administration tasks, and about how these times change as a consequence of the MPA. Studies of natural resource management policies in terrestrial settings reveal that transaction costs can be substantial. For example, transaction costs borne by public agencies have been estimated at roughly 30% of total program cost (McCann et al. 2005).

Discussion

Global MPA coverage will continue to increase as more countries expand their MPA network, prompted in part by international agreements, such as the Aichi Biodiversity Targets (CBD 2010). Economic assessments can help in the design and location of new MPAs so they deliver the greatest benefits. Previous assessments of the economic costs and benefits of MPAs have often focused on measuring the impacts of MPAs on fish, as the most obvious targets of extractive activities. This limited approach overlooks the wider impacts of MPAs on the marine

Table 1. Overview of the key challenges in estimating the economic benefits and costs of marine protected areas (MPAs).

Challenge type	Specific to an economic benefit or cost	Key challenges	Resolution	References
Methodological	Ecological and market benefits	Ability to identify the with-vs.-without impacts of MPAs	Bioeconomic model to simulate with-MPA and without-MPA scenarios	Sanchirico and Wilen (2001), Ferraro et al. (2019)
		Satisfying excludability assumptions	Randomize MPA location; conditioning strategies (e.g., regression or matching estimators); panel designs; and simulation modeling	Ferraro and Hanauer (2014), Ferraro et al. (2019)
		Satisfying no-interference assumptions	Narrow unit of assessment; partial identification; experimental or quasi-experimental saturation designs; vary spatial unit of analysis	Ferraro et al. (2019)
		Identifying appropriate control sites to serve as counterfactuals	Sample along a spatial gradient and conduct long-term monitoring	McCook et al. (2010), Caselle et al. (2015), Ferraro et al. (2019)
		Management characteristics can confound assessments	Control for management characteristics, for example, operating budget, level of protection	Claudet (2017)
	Market benefits	Discerning between domestic and international consumers	Cannot be achieved using standard economic methods. Revealed-preference methods can capture these differences in non-market values	Ahmed et al. (2007)
		Understanding the impact of shifts in the demand curve	Bioeconomic model to understand causal links between MPA establishment and generation of commercial benefits to businesses	Sanchirico and Wilen (2001)
		Capturing second-order impacts, for example, multiplier effects of tourism expenditure	Multi-market model, or input:output model of whole economy	Dyck and Sumaila (2010)
	Market and non-market benefits	Risk of double counting benefits	Clearly identify which benefit types are captured in the studies used as source evidence. Where this is uncertain, adopt a cautious approach to avoiding double counting	Fu et al. (2011)
	Non-market benefits	Avoiding hypothetical bias in survey-based approaches	Indicate that results of the survey will be consequential by explaining that they will be provided to relevant government agencies	Johnston (2006), Johnston et al. (2017)
		Respondents may have inadequate knowledge or understanding of MPA impacts	Provide information about the aspects of an MPA that are being valued, and assess respondent's knowledge and response-certainty so that these can be controlled for when modeling preferences	Burton et al. (2015), Aaneson et al. (2015)
	Establishment and maintenance costs	Costs vary depending on objectives and attributes of MPAs	Clarify and formalize MPA objectives	Claudet (2017)
		Difficulty predicting how long an MPA will take to establish	Adopt a precautionary approach and use upper and lower bounds from published estimates	Balmford et al. (2004), Gravestock et al. (2008), Ban et al. (2011), McCrea-Strub et al. (2011)
	Compliance costs	Difficulty identifying the next best opportunity available to displaced businesses	Conduct financial analysis of the opportunities available to the businesses	Hughes et al. (2016)
		Selecting a discount rate to assess future MPA benefits	Follow advice of published BCA guidelines (H.M. Treasury 2018)	H.M. Treasury (2018)

(Table 1. Continued.)

Challenge type	Specific to an economic benefit or cost	Key challenges	Resolution	References
		Subsidies to fishers distort opportunity costs	Factor out subsidies; use a bioeconomic model to analyze fishers' optimal management decisions in the absence of subsidies	Sumaila et al. (2010)
Data limitations		Data may not exist to support quantitative estimates of ecological and fishing outcomes	Further research: increased sampling of ecological metrics, including species' abundance, richness and diversity, across a range of spatial gradients and through time; and population modeling	Newman et al. (2006)
		Lack of relevant non-market valuation studies, such that quantification of non-market benefits is limited	Further research: Increase in non-market valuation studies would expand our understanding of how MPAs generate benefits to the community	Davis et al. (2019)
		Government and fisher records need to be readily available so that community benefits and industry baselines regarding catch levels are known	Standardization of reporting for (1) fisheries data and (2) government marine expenditures	Iacona et al. (2018)
		Existing cost data may be highly aggregated	Standardization of reporting for (1) fisheries data and (2) government marine expenditures	Iacona et al. (2018)

environment and prevents these wider impacts from being reliably quantified. Here, we have outlined best practice for MPA managers to assess the economic costs and benefits of MPAs. This assessment should also assist managers to design MPAs so that they can accurately assess their economic benefits through time—understanding how MPA impacts change over time can help avoid inefficient MPA designs and unnecessary opposition from affected fisheries (Brown et al. 2015). Furthermore, this assessment can assist managers to design MPAs that have the greatest chance of providing net benefits.

Any assessment of the economic costs and benefits of MPAs must (1) estimate the with-vs.-without benefits of an MPA (Fig. 2); (2) correctly apply discounting to allow comparison of values at different times; and (3) avoid inadvertently double counting the same benefits in different forms, for example, double counting revenues from MPA tourism as estimated benefits to business and to government (through taxes).

However, there remain challenges that impede best-practice evaluation, summarized in Table 1. These include a range of methodological issues: knowing which economic methods to use to estimate particular types of benefits and costs; the difficulty of discerning between domestic and international consumers; avoiding hypothetical bias in survey-based approaches; and appropriately accounting for the opportunity cost of MPA establishment. There will also be limitations to the analyses that can be performed based on available data. For example, there may be no data to support quantitative estimates of ecological and fishing outcomes, or difficulties sourcing reliable economic data to estimate costs. Often, there may be no relevant non-market valuation studies to understand non-market benefits. In some cases, these challenges could be addressed by additional research, for example, increased sampling of ecological metrics, including species' abundance, richness, and diversity, across a range of spatial gradients and through time. This will facilitate further empirical work to quantify causal links between MPA establishment and MPA's market benefits or opportunity costs. There is a general need for government and fisher records to be readily available so that community benefits and industry baselines regarding catch levels are known. Finally, an increase in non-market valuation studies would greatly expand our understanding of how MPAs can contribute welfare improvements.

We have emphasized that economic assessment of MPAs is not just about estimating costs. It is about considering both benefits and costs to support better decision making, recognizing that some of the benefits will not be market-based. There are many elements to consider when designing new MPAs, including local communities, ecological conditions, and political objectives or constraints (Burt et al. 2018). Different success criteria may be appropriate for different socio-economic settings. For example, designing an MPA based on strict economic efficiency may not always be desirable. Instead, the primary objective for a reserve may be to increase community capacity or enhance equality of access to marine resources (Gurney et al. 2015). These objectives need to be known a priori so that the relevant success criteria can be developed and baseline data collected (Claudet 2017).

In this review, we have provided an overview of how the economic costs and benefits of MPAs can be assessed. Economic assessments can assist decision makers to evaluate whether an MPA provides benefits in excess of costs, to quantify the distribution of benefits and costs among stakeholders, and to identify which MPA designs or locations offer the best value for money. Economic assessments provide a whole-of-community perspective that can otherwise be difficult to achieve. Understanding the distribution of benefits and costs across society helps identify policy options that will ensure equitable outcomes. As the number of economic studies focusing on the benefits and costs of MPAs grows, it will become easier for governments to realistically evaluate these issues and for economists to provide subsequent analyses.

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