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Ecological and Socio-Economic Effects of Highly Protected Marine Areas (HPMAs) in Temperate Waters

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This study provides a synthesis of current scientific evidence on the ecological and socio-economic effects of highly protected marine areas (HPMAs), primarily in temperate waters. The aim was to establish if HPMAs can provide benefits beyond those afforded by other types of marine protected area (MPA). We identify critical interactions within and between ecological and socio-economic effects to help marine planners and managers make informed decisions about the trade-offs of alternate management actions or measures for MPAs. Well-designed and enforced MPAs with high levels of protection (HPMAs) often provide conservation benefits within their boundaries beyond those afforded by other types of MPA. Much remains to be learned about the socio-economic effects of HPMAs. Empirical evidence to date suggests that potential benefits cannot all be maximised simultaneously because potentially conflicting trade-offs exist not only between but also within ecological and socio-economic effects. Marine planners and managers must be able to evaluate the impact and distribution of trade-offs for differing management regimes; to make informed decisions about levels of protection required in MPAs to ensure sustainable use of marine resources and meet conservation objectives. One of the main challenges remains providing evidence of the societal benefits from restricting use in these areas.

Keywords: HPMA, highly protected marine area, evidence, benefits, ecological, socio-economic, management, decisions

INTRODUCTION

Designation of marine protected areas (MPAs) is part of a global approach to using marine resources and biodiversity sustainably (Wood et al., 2008). The International Union for Conservation of Nature [IUCN] (2008) defines an MPA as 'a clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values.' This definition prioritises nature conservation and protection of associated ecosystem services.

The level of protection required depends on the ecological goals of the MPA, the condition of the site, and the level of activities occurring in an area (Sciberras et al., 2013). A continuum of different management measures can be used in MPAs, ranging from minimal intervention (e.g., restriction of particular activities or periods) to total prohibition of direct human activities that may affect biota (e.g., no-take areas). MPA management has often treated MPAs as multi-use areas with multi-use approaches based on the concept that the living resources can be impacted and/or exploited without compromising their sustainability.

One of the main challenges when establishing MPAs is demonstrating the societal benefits they provide if use is restricted. There is a long tradition of free access and diversity of uses, particularly in coastal areas, so MPAs can often be contentious, e.g., when users deem existing management to be adequate (Kearney et al., 2012). The direct and indirect impacts of activities on ecosystems are complex and sometimes unclear and stakeholders may argue such uncertainties are a reason for maintaining the *status quo*. Conversely, stakeholders supporting the designation argue that a precautionary approach is necessary to prevent future or ongoing damage that is not yet measured. Whilst some may see sustainable impacts as a justifiable target, others may consider the unimpacted state as more appropriate (Jones, 2014 and references therein).

Designating MPAs with higher levels of protection implies that more restrictive management measures will be likely, so it is important to consider how the benefits for conservation and associated ecosystem services compare with less restrictive management measures. We refer to the former as highly protected marine areas (HPMAs), defined as 'a geographical space that is protected from all locally manageable damaging or disturbing activities.' The structure and functions of the environment in HPMAs exist or develop in the absence of manageable human disturbance, and species and habitats develop or recover to the extent that they are not affected by manageable human pressures. HPMAs include, but are not limited to, no-take areas.

Studies of ecological and socio-economic aspects surrounding MPAs have proliferated over the past decade, providing data on their effects for a wide range of geographic locations, habitat and biota. Meta-analyses and systematic reviews of contemporary and historic ecological studies have been carried out using data mostly from tropical waters, but increasingly from temperate waters. Currently missing is an overview of the evidence to establish whether HPMAs, especially those in temperate waters, can provide ecological and socio-economic benefits beyond those afforded by other types of MPA. We address this gap by synthesising existing evidence on the ecological and socio-economic effects of HPMAs, particularly in temperate waters. The specific aims were (i) to establish whether such areas can provide benefits beyond those afforded by other types of MPA in temperate waters, and (ii) to help managers evaluate trade-offs between delivery of one benefit relative to the delivery of others.

WHAT IS AN EFFECT?

Effects of HPMAs fall into two broad categories (see definitions in **Supplementary Tables S1**, **S2**): effects on natural systems (ecological effects) and on society and the economy (socio-economic effects). For conservation purposes, HPMAs protect species and habitats inside protected areas, similar to terrestrial conservation areas. We therefore refer to an effect when there is a change in the abundance or condition of biota or habitat inside the HPMA, and associated ecosystem services, relative to comparable areas outside. Although the export of beneficial effects to areas outside is rarely an explicit objective of an HPMA, we consider such export an added effect. Socio-economic 'use' benefits include the direct and indirect contributions of HPMAs to human well-being. HPMAs also have 'non-use' and 'option use' benefits.

EVIDENCE ON ECOLOGICAL AND SOCIO-ECONOMIC EFFECTS

Studies of the ecological effects of HPMAs have been increasing. These provide insights for a range of geographic locations, habitats and biota. We used several sets of key publications to review the ecological evidence, including: primary peer-reviewed scientific literature, meta-analyses, systematic reviews, case studies from temperate waters, and long-term studies from around the world.

Existing studies on HPMAs tend to focus on the ecological effects of no-take areas on fish. The focus on ecological effects is often driven by the rationale for designation for species and habitat protection. Except for studies on the impacts of no-take areas on fisheries, there are currently no meta-analyses or systematic reviews indicating whether HPMAs provide additional economic benefits relative to other types of MPA. Economic effects of MPAs are generally assessed according to current and future direct and indirect use and non-use benefits. We combined the two approaches when assessing socio-economic effects of HPMAs. Where specific socio-economic evidence was lacking, we followed the approach of Turner et al. (2014) and used ecological literature to infer socio-economic effects of HPMAs but recognising non-linearities in the transformation of an ecological effect into a socio-economic effect (Koch et al., 2009).

Ecological Effects

Highly protected marine areas affect species and habitat within and outside their boundaries (**Table 1**). In their meta-analysis of 149 HPMAs from 29 countries, Lester et al. (2009) showed that they resulted in increases (on average) in organism size, density, biomass and species richness within their boundaries, though not for all taxonomic groups. Similarly, a meta-analysis using data from standardised surveys in 40 countries on shallow reef fish densities and sizes (Edgar et al., 2014) revealed that HPMAs contained more than five times the total biomass of large fish and 14 times the shark biomass compared with unprotected areas.

Temperate HPMAs have been found to show similar, positive biological responses for reef habitat compared with tropical ones (Stewart et al., 2009; Harasti et al., 2018). Positive biological responses have also been shown to be greater in HPMAs than in areas receiving less protection. In Europe, largest increases were reported within HPMAs; for biomass and density of organisms ranging from invertebrates to fish, with moderate increases in individual size and species richness (Fenberg et al., 2012).

TABLE 1 | Examples of key ecological effects and associated socio-economic effects attributed to highly protected marine areas (HPMAs, see text for details).

Species and habitat	Ecosystem services
On average, many fish, invertebrate and seaweed species increase in biomass, density, size and species diversity inside tropical and temperate HPMAs (Lester et al., 2009; Fenberg et al., 2012, Sciberras et al., 2013; Edgar et al., 2014, Guidetti et al., 2014; Di Franco et al., 2016, Harasti et al., 2018). Some fish and invertebrate species decline inside HPMAs as a result of competitive or predatory interactions (Micheli et al., 2004).	Direct use benefits (fisheries, recreation, tourism), resulting from the higher level of species and habitat protection in HPMAs, are probable (Wielgus and Bennett, 2009; Mangi et al., 2011; Costello, 2014; Di Franco et al., 2016) but may not be realised if management measures in HPMAs preclude those activities, except for spill-over effects (see below). Direct use benefits can lead to financial benefits in the supply chain (Hunt, 2008).
Tropical (Russ et al., 2015) and temperate (Sheehan et al., 2013) reef habitat structure and function recover inside HPMAs in the short- to long-term (Babcock et al., 2010).	Improvement in the condition of habitat that is known to provide regulating services (e.g., nutrient cycling, protection from erosion etc.) can be expected to increase the provision of those specific services.
Spill-over of multiple target and non-target species from protected areas to areas outside can lead to increased community complexity and species diversity within HPMAs and in nearby areas in both tropical and temperate areas (Halpern et al., 2010; Russ and Alcala, 2011).	Larger lobsters, caught outside no-take zones in the North-West Mediterranean (Goñi et al., 2010), offset the loss of catch from the reduction of fishing grounds. However, this effect may only occur if fish stocks are severely depleted to begin with (Buxton et al., 2014).
Modelled displaced fishing pressure leads to location- and species- specific effects on the biomass, production and species richness of non-target benthic species and their communities outside HPMAs (Hiddink et al., 2006).	Displacement of activities are likely to result in conflict with other users, and potentially disproportionate effects on some users due to exclusion (Mangi et al., 2011).

Surveys of rocky-reef fish assemblages in well-enforced HPMAs, partially-protected MPAs and fished areas at 30 locations across the Mediterranean revealed significantly higher fish biomass in HPMAs compared to partially and unprotected areas (Guidetti et al., 2014). At smaller spatial scales, species richness was significantly greater within HPMAs compared to areas affording no or lower levels of protection.

From a synthesis of empirical studies across a range of geographic locations worldwide, Lester and Halpern (2008) found a statistically significant difference in the overall density of organisms between HPMAs and partially protected areas. Sciberras et al. (2013) reported that partial protection increased fish biomass in those areas by approximately 50%, whereas HPMAs had double the biomass. Higher levels of protection did not increase fish species diversity.

Synthesising data from 20 studies of coastal fish assemblages in 31 temperate and tropical HPMAs, Micheli et al. (2004) revealed that up to a third of species in different studies were negatively affected by 25 years of protection. Their abundance in HPMAs was half or less than those in unprotected areas, resulting from increased densities of their predators or competitors within protected areas. Negative effects of protection on some non-target, low mobility species (i.e., prey) within HPMAs may thus not become apparent until a new equilibrium has been reached.

Most data used in meta-analyses assessing the ecological performance of HPMAs are from ‘inside versus outside’ comparisons (**Table 1**). A general positive effect on species and habitat observed inside HPMAs may be caused by displacing human activities such as fishing from within protected areas to areas outside. The effects of pressure displacement are location- and species-specific. Modelled area closures of different sizes and in different locations have shown both positive and negative effects on the predicted aggregate state of non-target species and their communities (Hiddink et al., 2006). These effects result from the trade-off between recovery in the closed area and additional (displaced) fishing effects in the unprotected areas. If the threat to an area is overfishing of target species, this may thus be more effectively dealt with by specific measures to curb fishing effort rather than to establish HPMAs (Boulcott et al., 2018; Hilborn, 2018).

Highly protected marine areas can increase the density of target species in temperate reef habitat (Sheehan et al., 2013). The cessation of destructive fishing methods, for example, allows for the recovery of biogenic habitat. This can increase recruitment and survival of species, such as scallops and fish. Quantitative analyses of long-term data collected from HPMAs in tropical and temperate reef habitat showed that in the short to medium term (i.e., within 5 years) habitat quality is improved and pre-harvesting population age and size structure is re-established (Babcock et al., 2010). The restoration of food web complexity due to increased species diversity and recovery of top predators, which are often targets of major fisheries, may take considerably longer.

Scientific consensus is emerging that increases in biomass of exploited species in HPMAs can lead to increased production of their eggs and larvae in the protected area (recruitment effect) and export of eggs and larvae from the area, as well as the net movement of adults (spill-over) to surrounding unprotected areas (Harmelin-Vivien et al., 2008; Stobart et al., 2009; Díaz et al., 2011; Follesa et al., 2011). Synthesising empirical evidence of adult spill-over, Halpern et al. (2010) demonstrated that HPMAs can benefit local fisheries adjacent to their boundaries and meet conservation objectives simultaneously, especially when spill-over of multiple species occurs. Russ and Alcala (2011) reported that, as communities of large predatory reef fish inside an HPMA in the Philippines increased in complexity, this complexity spilled over the boundary into adjacent unprotected areas.

Socio-Economic Effects

Socio-economic effects related to direct use benefits (e.g., fisheries, tourism) resulting from the higher level of species protection in HPMAs has been described for temperate and tropical HPMAs (**Table 1**). However, direct use benefits will not be realised if all activities occurring within an HPMA are excluded.

Mangi et al. (2011) recorded increased landings from inside (static gear) and outside (mobile and static gear) a closed area in the United Kingdom 2 years after closure to mobile gears. In the Columbretes Island Marine Reserve (north-west Mediterranean Sea), lobster catch due to spill-over offset the loss of catch resulting from the reduced area of fishing grounds. This generated a mean annual net benefit of 10% of the catch in weight after 8 to 17 years of protection (Goñi et al., 2010). However, Hilborn et al. (2006) and Buxton et al. (2014) cautioned that spill-over effects may not necessarily be an additional benefit due to increased fishing effort outside the protected area. The authors also reported that additional benefits from spill-over effects only occurred when fish stocks were severely depleted. Pantzar et al. (2018) found limited empirical evidence of economic spill-over benefits to fishermen and concluded that this economic benefit can only be considered anecdotal at this point. This view is echoed by Caveen et al. (2015).

Highly protected marine areas may provide financial benefits from direct use for recreation and tourism (**Table 1**). Costello (2014) reported that improvements in species diversity in the Leigh Marine Reserve (New Zealand) led to increased visitor numbers, with ecotourism in the area valued at NZ$8 million. Wielgus and Bennett (2009) found that SCUBA divers were willing to pay $5 to $10 more per day to visit a dive site in the Loreto Bay National Marine Park (Mexico) that had a higher number of large fish and a higher diversity of coral reef species than areas outside. Such direct use benefits can lead to financial benefits in the supply chain. Participation in recreational activity can increase demand and spending for support services such as accommodation and food. Hunt (2008) reported positive financial effects due to visitor spending in the Cape Rodney-Okakari Point HPMA (New Zealand). The estimated annual value added attributed to recreational activity spending was NZ$8.2 million, greatly exceeding the annual cost of managing the reserve (approximately NZ$70,000).

Benthic filter feeders such as oysters provide indirect use benefits including coastal defence, carbon sequestration and water quality regulation (Grabowski et al., 2012). Improvements in the maerl habitat in Lamlash Bay (United Kingdom) led to an increase in the abundance of juvenile scallops (Howarth et al., 2011). Improvements in the Lyme Bay (United Kingdom) reef habitat resulted in an increase in the diversity and biomass of benthic species (Sheehan et al., 2013). Both can be considered HPMAs in terms of the description used here. Whether the protection of habitats colonised by filter feeders enables the continued provision of indirect use benefits in HPMAs compared to those of other types of MPA, however, has not been proven.

Non-use and option use benefits attributable to MPAs are increasingly recognised. Positive willingness to pay for the protection of deep-sea habitat and species (Wattage et al., 2011; Jobstvogt et al., 2014), for example, that currently have no direct use for society indicates non-use benefits. It is uncertain if these are higher for HPMAs than for other types of MPA. The increased production and export of eggs and larvae of target species in HPMAs, for example, suggest higher option values than MPAs that do not generate these ecological effects.

COMPLEX INTERACTIONS WITHIN AND BETWEEN EFFECTS

Ecological and socio-economic effects of high levels of protection are influenced by many factors, including area design (e.g., size and location), age, habitat and species within the area, the management regime, the effectiveness of enforcement, baseline conditions and how activities outside the protected area are managed (e.g., Mora and Sale, 2011). These factors interact in complex ways to influence nature conservation and the delivery of associated ecosystem services (**Table 1**).

Managers seeking to sustain and enhance ecosystem services afforded by HPMAs, or indeed other types of MPA, can conserve existing species and habitats delivering these services and/or restore elements which have been lost or damaged (Koch et al., 2009). Each option involves interactions between and within their various ecological and socio-economic effects (**Table 2**). Desired effects may be mutually exclusive (e.g., protection of vulnerable species or sensitive habitat may preclude commercial trawling and vice versa). In some cases, interactions are less severe or absent (e.g., fishing and recreational activities can occur in the same locations, but fishing might have a negative effect on some types of recreation such as diving).

Due to the multitude of human activities that take place in marine environments, the distribution of effects of HPMAs differs amongst stakeholders. Notwithstanding the costs of monitoring and management, costs will be incurred by those whose activities are restricted; often in the form of market values measured in terms of loss of income. Conversely, benefits will be achieved by direct and indirect use as well as by non-use; these

TABLE 2 | Illustrative examples of interactions within and between ecological and socio-economic effects of highly protected marine areas (HPMAs), based on evidence in the available scientific literature (see **Table 1**).

Type of interaction		
Ecological – Ecological	**Ecological – Economic**	**Economic – Economic**
Synergistic: Improvement of habitat condition leading to increased species numbers and diversity (Fenberg et al., 2012).	Synergistic: Increased species diversity leading to increase in recreational activity (Costello, 2014).	Synergistic: Higher species diversity leading to increased participation in recreational activities and demand for support services (e.g., accommodation, food and drink) (Hunt, 2008).
Antagonistic: Increase in target species abundance vs. reduction in prey species due to increased predation (Babcock et al., 2010).	Antagonistic: Increase of one target species vs. decrease in another target species due to predation (Babcock et al., 2010).	Antagonistic: Displacement of mobile fishing gear may create conflict with static gear (Mangi et al., 2011).

include both market and non-market values. As demonstrated in **Table 1**, there is a time lag between designation and observed improvements within and outside HPMAs. Over time, this will lead to intergenerational flows of benefits and costs; e.g., benefits might be realised in the long-term but with costs arising in the short-term (Charles and Wilson, 2009).

IMPLICATIONS FOR FUTURE DECISION-MAKING ON HPMAs

Decisions surrounding HPMAs involve scientific evidence and a shifting range of and balance between social, political, legal, cultural, economic and environmental concerns (Schratzberger, 2012; **Supplementary Figure S1**). The wide range of competing concerns and the implied higher levels of protection in HPMAs means that, to be effective, decision-makers need to maximise the quality of their evidence.

Scientific evidence shows that well-designed and enforced HPMAs can provide conservation benefits beyond those afforded by other types of MPA. There is potential for additional socio-economic benefits from HPMAs (as well as multi-use MPAs), contingent on the baseline ecological condition, if activities with minimal disturbance (e.g., hand-collection of shellfish) are allowed, and time lags of effects. Therefore, interactions between and within ecological and socio-economic effects require the decision-making process surrounding HPMAs to recognise and highlight trade-offs to stakeholders.

In summary: Well-designed (e.g., McLeod et al., 2009) and enforced HPMAs can provide additional conservation benefits. Robust reviews of HPMAs, in predominantly temperate waters, demonstrate that such areas can deliver conservation benefits, especially within their boundaries, beyond those afforded by other types of MPA. Effectively managed HPMAs can result in increased biomass, density and diversity of species and in the recovery of habitat, exceeding that achieved by some partially protected areas. The evidence base supporting additional socio-economic benefits is less well-developed. Some ecological benefits may translate to economic benefits; as shown by increases in fisheries landings and profitability, and/or increased public participation and spending in recreational activities within HPMAs. However, socio-economic benefits are contingent on baseline conditions and the activities allowed to occur within and around HPMAs. Non-use and option use benefits may also exist but have yet to be proven empirically.

Interactions between and within ecological and socio-economic effects require trade-offs in the decision-making process. Although primarily conceived to conserve species and habitats, HPMAs are often expected to achieve an increasingly diverse set of conservation, social and economic goals (Watson et al., 2014). The setting of these goals must acknowledge the potentially conflicting interactions, and hence trade-offs, between nature and society. These trade-offs mean that not all benefits can be maximised simultaneously. Since stakeholders need to make informed decisions about their relative preferences (Koch et al., 2009; Lester et al., 2013) and stakeholder support is key to successful implementation and management (Di Franco et al., 2016; Ban et al., 2017; Woodcock et al., 2017; Giakoumi et al., 2018), marine managers must be able to explain the impact and distribution of these trade-offs for differing management regimes.

Every MPA is unique. MPAs differ in the ecological and socio-economic contexts in which they are situated, the objectives for which they were designated, the level of enforcement etc. This has led to diverse outcomes that represent an opportunity to learn more about the potential promises and limitations of MPAs (Pendleton et al., 2017). We need to fully use these experiences to understand when and where HPMAs can best be used to achieve desired outcomes.

AUTHOR CONTRIBUTIONS

MS was lead author on the manuscript. MS and LP led the research on ecological and socio-economic evidence. All authors contributed toward project design and research, a stakeholder workshop, interpretation of the findings, and the manuscript.

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SUPPLEMENTARY MATERIAL

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