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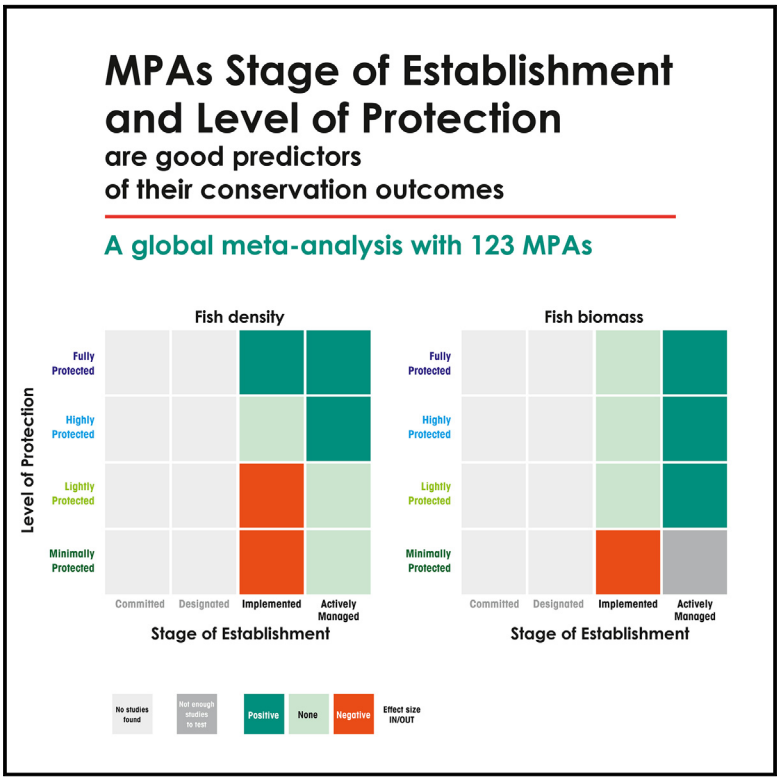
Marine protected areas stage of establishment and level of protection are good predictors of their conservation outcomes

Graphical abstract



Highlights

- First study linking the MPA guide levels and stages directly to ecological outcomes
- Actively managed and strongly regulated MPAs can succeed in recovering fish
- Implemented MPAs that are minimally protected show detrimental outcomes for fish
- We call for using the MPA guide criteria in understanding global coverage of MPAs

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In brief

Global targets should track MPA quality and quantity. This is the first study using a new science-based framework across 123 MPAs and tying levels of protection and stages of establishment directly to outcomes. Actively managed MPAs have positive outcomes, whereas those only implemented do not. Implemented MPAs that are minimally protected show detrimental outcomes for fish. “Strict protection” could refer to fully protected or actively managed, highly protected areas. We call for using the MPA guide to understand global coverage.

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Marine protected areas stage of establishment and level of protection are good predictors of their conservation outcomes

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SCIENCE FOR SOCIETY Currently, there is a global commitment to improve ocean health by covering 30% of the ocean with effective marine protected areas (MPAs) by 2030. Here, we tested, for the first time, the effects of both levels of protection and stages of establishment of a new science-based framework—the MPA guide—in the recovery of harvested fish across 123 MPAs globally. Our findings reflect the important interplay between levels and stages and tie them directly to conservation outcomes. Actively managed MPAs, with evidence of monitoring and enforcement, have more positive ecological outcomes than those that are only implemented. Studied MPAs show they need to be actively managed and strongly regulated to effectively recover fish, while implemented MPAs that are minimally or lightly protected can lead to detrimental outcomes. We call for using standardized and comparable criteria in understanding global coverage to track MPA quality as well as quantity.

SUMMARY

Despite the importance of active management and strong protection in driving marine protected areas (MPA) performance, coverage area remains the sole indicator for global targets. To assess whether conservation quality lags behind quantity, we conducted a global meta-analysis of 123 MPAs. We show that MPAs' Levels of Protection and Stages of Establishment are reliable proxies for MPAs' ecological outcomes; hence, they are good candidates for tracking MPA quality. Actively managed MPAs have significantly higher fish density and biomass than non-protected surrounding areas, while MPAs that are only implemented do not. The effectiveness of actively managed MPAs can be maximized if they are fully or highly protected. Lightly and minimally protected areas that are only implemented can deliver negative outcomes. Our findings highlight the important interplay between stages and levels as developed in the MPA Guide and support the need to include both in conservation targets to track not only MPA quantity but also quality.

INTRODUCTION

Marine protected areas (MPAs) are a central area-based conservation tool for most nations to reach target 3 of the recently agreed Kunming-Montreal global biodiversity framework, which calls for conserving at least 30% of ocean areas by 2030.[1] Progress toward this target has been biased toward metrics of quantity, ignoring the quality of protection.[2,3] The capacity of MPAs to deliver their intended main outcome— – which is, by definition, the maintenance and/or

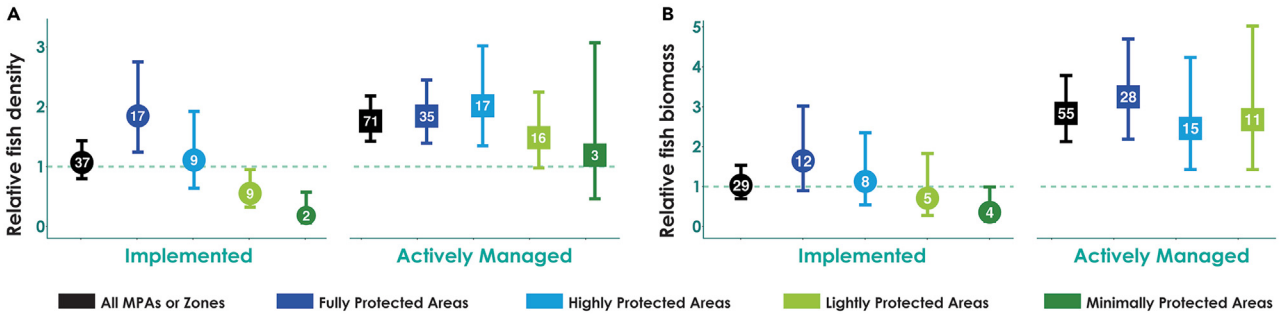

Figure 1. MPA's ecological effectiveness by Stage of Establishment and Level of Protection

Ecological effectiveness of classes of marine protected area (effect sizes) per Stage of Establishment and Level of Protection for fish density (A) and biomass (B). The horizontal dotted line at 1 represents equal fish density (or biomass) inside and outside of the MPA or zone; values greater than 1 indicate more fish (or more biomass) within the MPA or zone; values below 1 indicate fewer fish (or less biomass) within the MPA or zone. The bars represent 95% CIs (p value < 0.05). Sample sizes (the number of the studied MPAs or zones) for each group are shown. In the figure, effect sizes and CIs (95% CI; p value > 0.05l) are back transformed from log-ratios.

recovery of relevant species, habitats, and ecological functions, and the associated ecosystem services[4]—depends on their capacity to curb threats to biodiversity within their boundaries.[5] There is now growing evidence from social and natural sciences showing that the level of protection is an important driver of MPA social-ecological effectiveness.[6–9] This has been recently captured in the MPA Guide framework,[10] which defines four Levels of Protection (i.e., fully, highly, lightly, and minimally protected; see methods) that build on Horta e Costa et al.[11] regulation-based classification system for MPAs.

How MPAs are managed is another important driver of their effectiveness. Management capacity,[12,13] compliance,[14] enforcement,[15,16] as well as stakeholders' engagement[17–21] are critical aspects of MPA success. The Stages of Establishment (i.e., committed, designated, implemented, actively managed; see methods), together with enabling conditions, of the MPA Guide framework also aims to capture these attributes.[10]

Until now, most MPAs reported in the World Database on Protected Areas have low protection levels or are just designated and not implemented in the water, and even fewer are actively managed.[3,22–27]

We conducted a global meta-analysis to assess how the Level of Protection and Stage of Establishment of MPAs align with their ecological outcomes. Our assessment is meant to promote not only quantity but also the quality of biodiversity conservation efforts and highlight the need to include these metrics in conservation targets.

RESULTS

Fish density and biomass

Stages of Establishment

Actively managed MPAs harbor, on average, a 1.7-fold higher fish density (E = 0.53 ± 0.23, 95% CI) and a 2.8-fold higher fish biomass (E = 1.04 ± 0.29, 95% CI) than adjacent unprotected areas (Figure 1). Protected areas that are only implemented have, on average, similar density and biomass than unprotected areas (E = 0.07 ± 0.31, 95% CI and E = 0.03 ± 0.39, 95% CI, respectively). (Meta-analysis test for residual heterogeneity: QE(df = 106) = 914,139.4, p value < 0.0001 for density and QE(df = 82) = 796,200.9, p value < 0.0001 for biomass).

Levels of Protection

On average, fully and highly protected MPAs host a 1.7- and 1.6-fold higher density (E = 0.55 ± 0.26, 95% CI and E = 0.49 ± 0.37, 95% CI), respectively, and a 2.7- and 1.9-fold higher biomass (E = 0.98 ± 0.35, 95% CI and E = 0.63 ± 0.46, 95% CI, respectively) than adjacent unprotected areas (Figure 2). Lightly protected areas, on average, do not host higher density (E = 0.06 ± 0.38, 95% CI) but can host higher biomass, although with higher variability around that mean effect compared to higher Levels of Protection (E = 0.58 ± 0.55, 95% CI). On average, minimally protected areas do not host higher density (E = −0.59 ± 0.83% CI) or biomass (E = −0.88 ± 0.98% CI) than unprotected areas (Figure 2). (Heterogeneity statistics: QE(df = 104) = 781,996.9, p value < 0.0001 for density and QE(df = 80) = 6790437.9, p value < 0.0001 for biomass).

Interaction between Stages of Establishment and Levels of Protection

Actively managed MPAs that are fully or highly protected are the only MPAs consistently delivering higher density and biomass compared to adjacent unprotected areas (Figures 1 and 3). Implemented MPAs, when fully protected, harbor higher density than and similar biomass to surrounding unprotected areas. Implemented MPAs that are highly, lightly, or minimally protected do not exhibit higher density or biomass compared to surrounding areas; in fact, minimally protected implemented MPAs had significantly lower fish density and biomass than outside areas (Figures 1 and 3; Table S3, supplemental materials for detailed statistics).

Lightly protected areas, if actively managed, harbor higher biomass but similar density than surrounding unprotected areas (Figures 1 and 3; Table S3, supplemental materials for detailed statistics). If only implemented, they do not provide positive conservation outcomes and can even lead to negative outcomes with lower density inside than outside those areas (Figure 1A). Minimally protected areas that are only implemented also lead to lower density and biomass inside than outside, while no differences are detected when actively managed (Figures 1 and 3; Table S3, supplemental materials for detailed statistics).

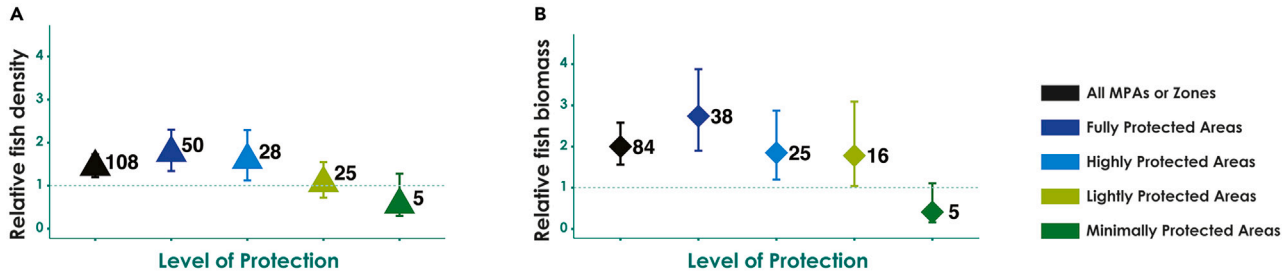

Figure 2. MPA's ecological effectiveness by Level of Protection

Ecological effectiveness of classes of marine protected area (effect sizes) per Level of Protection for fish density (A) and biomass (B). The horizontal dotted line at 1 represents equal fish density (or biomass) inside and outside of the MPA or zone; values greater than 1 indicate more fish (or more biomass) within the MPA or zone; values below 1 indicate fewer fish (or less biomass) within the MPA or zone. The bars represent 95% confidence intervals (p value < 0.05). Sample sizes (the number of the studied MPAs or zones) for each group are shown. In the figure, effect sizes and confidence intervals (95% CI) are back transformed from log-ratios.

Interactions with MPA age and size

Older and larger MPAs that are actively managed are more likely to harbor more and larger fish compared to adjacent outside areas than younger, smaller, and implemented MPAs (Table S4). A similar pattern was found for older MPAs that are fully protected, yet MPAs that are minimally protected are likely to increase their negative effects over time. Highly protected MPAs are likely to harbor more fish density and biomass than outside when they are larger, like minimally protected MPAs, but for fish biomass only (Table S4). Yet, this was not recorded for larger, fully protected areas (Table S4).

DISCUSSION

Our findings reflect the important interplay between Levels of Protection and Stages of Establishment and suggest that the combined information on both is important to contextualize ecological monitoring outputs and, when resources are scarce, can act as a proxy for MPA conservation outcomes. A new important finding of this study is that actively managed MPAs, which show evidence of monitoring and good enforcement, have significantly more positive ecological outcomes than those not actively managed (implemented only).

Both Stages of Establishment and Levels of Protection matter

Here, we show that the studied MPAs need to be actively managed and strongly regulated to succeed in recovering harvested fish. Indeed, based on the available studies, only actively managed MPAs that are fully or highly protected can provide significant ecological outcomes for fish density and biomass. MPAs that are only in the implemented stage did not host greater density or biomass inside than outside, except in the case of fully protected areas and only on fish density. While previous studies have already highlighted the role of strong regulations in MPA ecological effectiveness,[9,28,29] we suggest here that good enforcement, monitoring, and appropriate *in situ* management may be even more important, particularly for areas that are not fully protected (e.g., highly protected areas that are only implemented did not harbor higher fish density, whereas fully protected areas did). Previous studies suggested that surveillance of fully protected areas is more cost effective than MPAs where fishing occurs, likely due to increased complexity in controlling fishing efforts or illegal fisheries.[30] Although highly protected areas may represent the best solution where fully protected areas are not ethically acceptable (e.g., in some nearshore and densely populated regions[13,31–33]), they must be actively managed and enforced to deliver similar expected ecological outcomes as fully protected areas. Yet, our results for highly protected areas also confirm recent findings that if well-regulated and staffed, multi-use MPAs may provide comparable outcomes to no-take MPAs.[13]

While lightly protected areas that are actively managed may also be able to provide higher fish biomass (but not density) than adjacent unprotected areas, which is an innovative and relevant finding, they can show significant negative effects (for fish density) if only implemented. Such contrasting results for lightly protected areas highlight the key role of implementation. They also suggest that some species may still benefit from strongly regulating moderate-impact fisheries if actively managed and with the remaining threats minimized and compatible with sustainable use—probably where fishing gears targeting most commercial fish species are banned or highly restricted from the MPA.[13,34]

Our findings strengthen previous studies showing that ecological outcomes depend on certain MPA conditions, such as regulations,[8,9,13] management capacity,[12,13] compliance and enforcement,[14,28] stakeholders' engagement, and awareness.[19,21] One of the main contributions of our study is that here, we use a composite framework to capture some of these management features together and show that it directly relates to MPA ecological success in protecting harvested fish.

Further, the significant difference between actively managed and implemented MPAs (for all MPAs together and per Level of Protection) suggests that [the jure] regulations—what is allowed or disallowed to occur within MPAs—become a good proxy of what is *de facto* occurring *in situ* in the actively managed MPAs. Indeed, regulations alone might not represent the impacts happening in implemented MPAs, as the same Level of Protection showed contrasting results in the two Stages assessed, reinforcing the need to report the Stages of Establishment as a relevant MPA quality metric.[3,27,35,36]

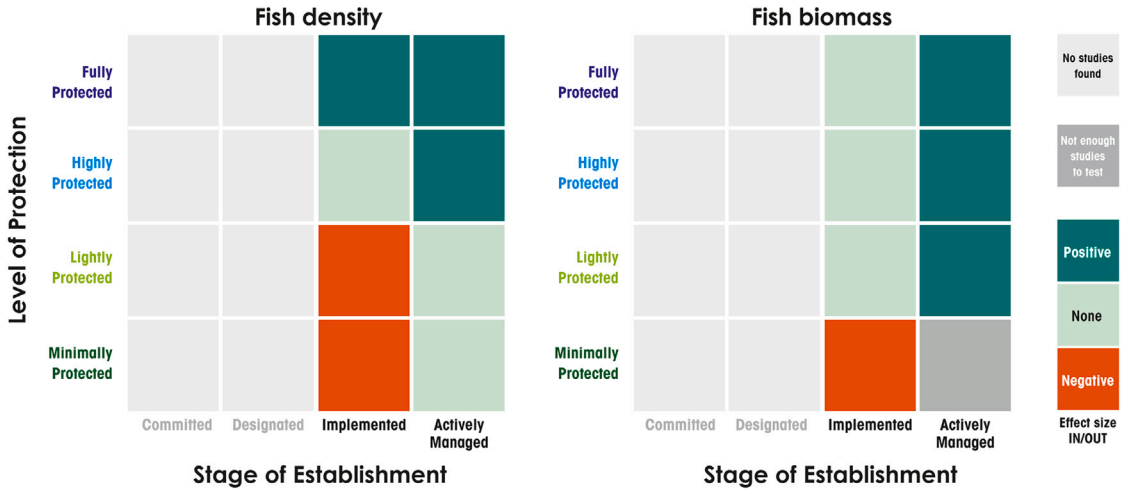

Figure 3. MPA Guide matrix of the Levels of Protection (vertical axis) and Stages of Establishment (horizontal axis) reflecting the meta-analysis results for fish density (left panel) and fish biomass (right panel)

Results are based on log-ratio effect sizes, *E*, i.e., mean density or biomass inside a protected area over mean density or biomass in the surrounding unprotected location (i.e., outside the MPA). A positive change means significantly higher fish density or biomass inside MPAs or zones compared to outside areas, negative change means significantly higher fish density or biomass outside compared to inside MPAs or zones, and none means no statistically significant differences were found inside vs. outside. The dark gray quadrat means that no studies were found to allow testing for the interaction effect; light gray quadrats relate to classes that are not expected to deliver outcomes as not implemented, and no studies were found in the literature review.

Low Levels of Protection can be detrimental to marine ecosystems within MPAs

Minimally protected MPAs that are not actively managed show significantly lower harvested fish density and biomass inside compared to reference areas outside the MPA. The same pattern was detected for fish density in lightly protected areas that are not actively managed. Such results suggest that these MPAs are not delivering their conservation goals but have a negative impact on harvested fish. In these MPAs, fishing and other uses may be prevalent or more impactful inside than outside. For example, more trawling or other damaging activities occur inside than outside some European MPAs.[5,24,37,38] This may be related to MPAs being commonly located in more biodiversity-rich and attractive sites for users,[39] raising concerns about the ability of MPAs to reduce threats, particularly in sensitive areas. Negative impacts are enhanced through time for the minimally protected areas, suggesting cumulative harm. Actively managed MPAs that are minimally protected do not show the same pattern but rather similar values between inside and outside, suggesting that they are not contributing to conservation goals. However, their active management stage is possibly avoiding increased threats inside these areas.

MPA quantity does not imply quality

The process of establishing MPAs typically requires a substantial social and political effort.[40,41] MPAs that are at low Levels of Protection or not actively managed may be misunderstood by local communities, who may expect ecological benefits that are not likely to be realized, including the recovery of harvested fish species. Some socioeconomic benefits afforded by protection depend on underlying positive ecological outcomes[6,31] and contribute to determining social acceptability and compliance.[20] Hence, MPAs that do not deliver positive outcomes may also limit the implementation and success of future MPAs in their regions.[14,17]

Stages of Establishment and Levels of Protection inform about MPA quality

As previous studies detected a diversity of key management features influencing ecological and social MPA performance,[13,19,21] it is critical to acknowledge the role of composite indices in capturing such mechanisms. Existing measures of management effectiveness are multifaceted (e.g., management effectiveness tracking tool[42]) but relatively complex to standardize and capture into simple metrics. Hence, most MPAs do not have these metrics consistently reported in global databases.[43] As a compromise between multi-criteria and simple objective metrics, our findings suggest that a summary of highly relevant management-related features known to drive MPA effectiveness is captured by the MPA Guide Stages of Establishment and Levels of Protection.

Limitations still exist

The limited number of peer-reviewed studies assessing ecological and social outcomes of MPAs with low Levels of Protection contributes to associated variability and limits high-confidence generalizations, reinforcing previous concerns of publication and research biases.[9,10] Further, few MPA studies employ rigorous study designs that account for other factors, i.e., many monitoring studies lack baseline data,[44,45] or some studies may focus on indicators (e.g., density/biomass) that are not linked to the MPA management goals. Further, coastal MPAs were primarily studied here, but open-water and deep-sea offshore MPAs may provide distinct results. MPAs assessed also did not cover all regions and biomes. Studying and publishing about other environments, including deep-sea areas or arctic

and sub-arctic regions, are central to capturing what is happening to those species and habitats under different protection and management regimes. The lack of consistent data on MPA outcomes for marine organisms other than finfish targeted by fisheries for the different Levels of Protection also limits understanding of the effects on other organisms. Additionally, averaging data from different depths, habitats, or species may underestimate the contribution of some species.[46] We recognize that our findings cannot represent all types of MPAs, monitoring techniques, or marine organisms, so caution is needed when generalizing results. Further, due to the limited sample size and available information on each MPA, we were unable to assess full interactions between Levels of Protection, Stages of Establishment, and other features known to affect MPA impacts (e.g., MPA age, size, enabling social-political context[9,10,47]). Importantly, here, Levels of Protection mostly rely on *de jure* regulations as a proxy to what is occurring *in situ*, whereas in other studies, they may reflect the existing situation. Finally, not all studies and MPAs display information matching the criteria of the MPA Guide Levels and Stages. Hence, despite our efforts to gather all the relevant data, missing information may have affected MPA classifications in some cases.

Our findings support calls for using standardized and comparable classification criteria to distinguish MPAs in understanding global coverage

This is the first study that explicitly uses a new science-based framework across a large number of MPAs and ties the Level of Protection and Stage of Establishment directly to outcomes. Despite some limitations, our results are central to informing MPA design both for future and existing MPAs.

The framework tested here is used around the world[48] and is being recommended as a mandatory indicator to track MPA quality in parallel with area coverage for target 3 of the Kunming-Montreal global biodiversity framework.[3,27,35] Our results can also guide the implementation of the 2030 European Biodiversity Strategy by supporting a definition of "strict protection" for EU waters. Our findings suggest that "strict protection" should include only fully protected areas or highly protected areas that are actively managed. We intend our findings to reinforce the urgency in tracking MPA quality with a common language in the global pursuit of more effective MPAs for a healthy ocean for nature and people.

METHODS

Data selection: Response variables and covariates

We conducted a global literature review of published studies on the links between MPA ecological outcomes, Level of Protection, and Stage of Establishment (up to March 2022; see supplemental materials, supplemental methods, and Table S1) to add to the studies already used by Zupan et al.[9]

We retained studies that reported density and/or biomass of fished species (i.e., commonly reported indicators of MPA ecological effectiveness) within single or multi-zone MPAs and in adjacent open access/unprotected areas.[9] For the meta-analysis, we used log-ratios as effect sizes, so we kept studies from which we could extract the mean, variance, and sample sizes (from plots, tables, or text). These were pooled at the MPA scale when displayed or analyzed at a finer scale (e.g., per depth, habitat types, juvenile or mature life stage, species) (see supplemental materials and Zupan et al.[9]). Studies that reported aggregated information on an MPA composed of multiple zones with different Levels of Protection were not included. Studies reporting conservation outcomes from different Levels of Protection from multi-use MPAs were considered separately. An insufficient number of studies reported results for species not targeted by fisheries for different Levels of Protection and Stages of Establishment, preventing us from testing for their effects, so these papers were omitted.

The final database consisted of 123 MPAs or zones worldwide (Figure 4 and supplemental materials, Table S2).

Each MPA (or zone in the case of multi-zone MPAs) was assessed to assign an MPA Guide Level of Protection of either full protection (i.e., a no-take area where impacts of all human uses are minimized), high protection (i.e., small scale, low impact, and selective uses), light protection (i.e., medium scale and moderate-impact uses), or minimal protection (i.e., large scale and high impact uses). The impact, number, and typology of the following seven activities were assessed: mining, dredging, anchoring, infrastructure, aquaculture, fisheries, and non-extractive recreational activities[10] (mpa-guide.protectedplanet.net). MPA Guide Level of Protection is based on the impact of activities occurring in an ocean area (as detailed in the expanded guidance for Level of Protection at mpa-guide.protectedplanet.net). Importantly, because of the broad nature of this meta-analysis and the difficulty in collecting information about impacts occurring in the water, Level of Protection here is largely based on published regulations and not de facto impacts occurring in the area. However, we considered what studies described about the *in situ* fisheries. Management plans or equivalent regulatory documents were also searched and screened to understand the regulated activities. When no information on a particular use was available, we assumed it was not allowed or had a low impact.

Similarly, each MPA (or zone in the case of multi-zone MPAs) was assessed to assign an MPA Guide Stage of Establishment of either proposed (i.e., the MPA is announced and committed), designated (i.e., the MPA is legally gazetted or equivalent; borders are known, some interim rules/prohibitions may exist), implemented (i.e., the MPA becomes operational in the water with a management plan or equivalent and some staff to implement it; the rules are made aware to communities), and actively managed (i.e., the MPA is monitored and management is evaluated, with changes made, when needed, to support social and ecological outcomes; there is community engagement and enforcement). The Stages of Establishment were extracted from the MPAtlas (mpatlas.org) assessments and complemented where needed with additional sources. The MPAtlas considers the MPA Guide minimum criteria for Stages: implemented MPAs are those with a management body and clear regulations that are made aware to users; actively managed MPAs are those with active/ongoing monitoring, community engagement, and management evaluation. Such criteria are searched for in available online sources and via the professional network of the MPAtlas team. When evidence of active management is not found, the MPA is assigned as implemented. In this study, we also checked for complementary

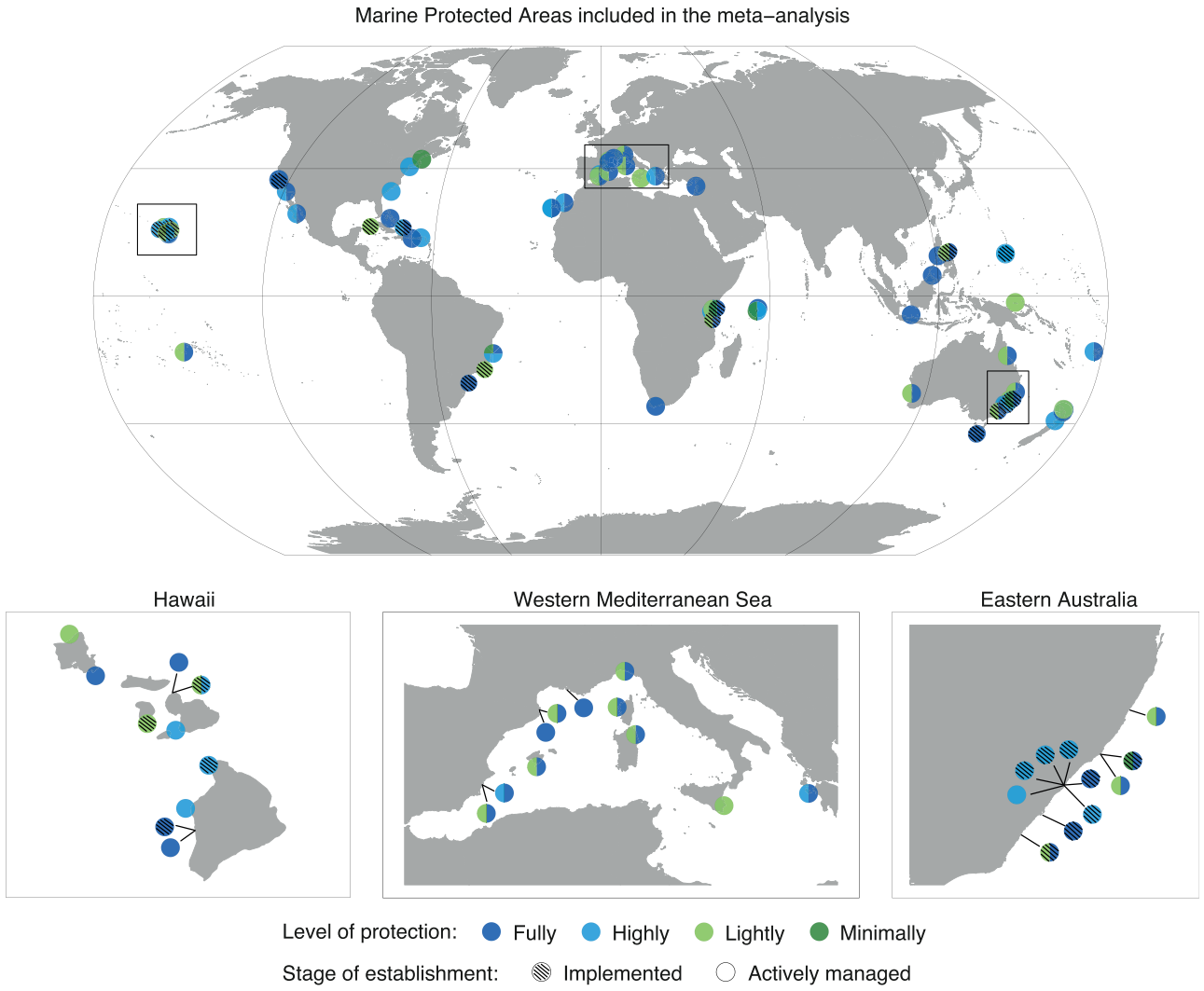

Figure 4. Location, Level of Protection, and Stage of Establishment of the case studies (*n* = 123) included in the meta-analysis
(More details in Table S2, supplemental materials.) Striped circles are MPAs that are implemented, and non-striped circles are the ones that are actively managed.

information (to overcome possible misassignments) in the studies included, in the management plans (all management plans or equivalent regulatory documents were screened to understand the regulation and management of activities), in online resources (e.g., MPA websites) and in contacts with local researchers (Australia, Hawaii, and Mediterranean). MPAs with reports of active, ongoing, and *in situ* management, monitoring, and adequate surveillance were considered actively managed. Although a criterion within the MPA Guide, we did not include community engagement for active management in our complementary search, as information was not consistently found for the MPAs considered. All MPAs in this study were considered implemented if they had management plans or equivalent (they all had evidence of having a management body). Good enforcement was not considered a requisite for implemented MPAs (i.e., some reported illegal fisheries or poor enforcement), but it was for actively managed MPAs.

Of the total 123 MPAs or zones, most were fully protected (57, with 24 being single-zone fully protected areas or FPAs), then highly protected (32), lightly protected (26), and minimally protected (8). The majority of the studied MPAs were considered actively managed (84), with the rest being implemented (39) (Figure 4 and supplemental materials, Table S2). In the studies retained and assessed (*n* = 49), no MPAs were found to be only committed or designated.

Meta-analysis

To assess how MPA conservation outcomes could be predicted or not by their Level of Protection and Stage of Establishment, we used a weighted mixed-effects meta-analysis to test for the effect of these factors alone (categorical moderators) and for the effect of their interactions (estimator: restricted maximum likelihood, REML; we weighted by sample size). The response to protection was modeled with log-ratio effect sizes

(E) consisting of species mean density or biomass inside a protected area over species mean density or biomass in the control unprotected location (i.e., surrounding areas outside the MPA). The effect size of each moderator level was obtained by subtracting the model intercept. A minimum of two MPAs or zones within each interaction category (i.e., Level of Protection and Stage of Establishment) was required to be included in the model (e.g., for fish biomass, only one actively managed and minimally protected area was found; hence it was removed from the respective model and plot). We followed the same meta-analytical approach as Zupan et al.[9] and Sciberras et al.[49] For visualization, log-ratios effect sizes and associated confidence intervals (CIs, 95%, p value < 0.05) were back transformed. Funnel plots and tests for asymmetry were run to test for sample bias (for Levels, Stages, and the interaction between stages and levels for fish density and biomass, Figures S1–S6, with significant bias only for fish biomass, p value < 0.05). The interactions between MPA age or log (size) (numeric moderators) and Level of Protection or Stage of Establishment were also tested. Due to the limited sample size and available information on different MPA types, the interactions between three moderators were not tested (similarly to other previous meta-analysis; Sciberras et al.[49]). All statistical analyses were performed using the metafor package (version 3.0-2)[50] in R software (R version 4.1.3).

RESOURCE AVAILABILITY

Lead contact

Requests or questions related to data, methods, or results can be made to the lead contact, Barbara Horta e Costa (bbcosta@ualg.pt).

Materials availability

The supplemental methods and detailed model results (Tables S3 and S4) are available in supplemental materials.

Data and code availability

The MPA dataset (Table S2, excel) and R script (Data S1) are available in the supplemental materials. Any additional requests can be made to the lead contact. AI was not used in any component of this study.

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AUTHOR CONTRIBUTIONS

B.H.C., J.C., and C.d.B.-A. planned the methodology and discussed the study; C.d.B.-A. did the literature review; C.d.B.-A. and B.H.C. searched for complementary information on the case studies; J.R. and E.F. supported the review of management plans and mapping, respectively. E.P. and N.H. retrieved the Stages of Establishment from the MPAtlas, and J.M. helped get the geographic locations of MPA centroids for mapping. B.H.C. and C.d.B.-A. analyzed the data and built the results. B.H.C. wrote the main draft, with contributions from all authors. All authors read and approved the content of the manuscript.

DECLARATION OF INTERESTS

The authors declare no competing interests.

SUPPLEMENTAL INFORMATION

Supplemental information can be found online at https://doi.org/10.1016/j.crsus.2025.100345.

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