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Entry fees enhance marine protected area management and outcomes

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ABSTRACT

Well-resourced marine protected areas (MPA) are better managed, leading to improved ecological outcomes. Tourism is often cited as an important source of financial support for MPA management, yet it is unclear whether funding from visitor entry fees improves the effectiveness of the world's MPAs. Here we ask whether fees to enter MPAs associate with enhanced fish biomass, a key ecological goal of many MPAs, and whether relations exist among entry fees and management effectiveness. In an analysis of 86 MPAs, we found entry fees were associated with greater fish biomass when compared to parks without entry fees, but only for parks with lower scores for management effectiveness. A global assessment of management survey responses from 214 MPAs suggested the hypothesis that MPA entry fees benefit budget security and staff capacity to carry out critical management activities. Together, the results suggest a mechanism whereby entry fees support greater capacity to educate parks users on rules and enforce those rules. Future work should look at the details of MPA budgets to unravel the relationship between funding, management activities and ecological outcomes. Dependency on tourism also comes with the important implication that declines in tourism caused by socio-economic shocks and geopolitical events may have affected the financial security and therefore possibly the ecological effectiveness of MPAs.

1. Introduction

Tourism can help meet many conservation and development objectives, including increasing local employment, public education, and biodiversity conservation in marine protected areas (MPAs) (Giakoumi et al., 2018). In particular, delivering positive ecological outcomes require more than just MPA designation, but also ongoing financial support for effective management (Gill et al., 2017; Edgar et al., 2014; Hargreaves-Allen et al., 2017; Giakoumi et al., 2018). The financial security of management is important to support effective MPAs, but the ongoing management costs often exceed government budgets for management (Bohorquez et al., 2019; Ban et al., 2011). Grants and funds from charities may support MPAs in the early stages of development, but donor funding is typically not a long-term option for financing management (e.g. Browne et al., 2022). A source of financial support that has often been sustained long-term is visitor entry fees (Depondt and Green, 2006; Terk and Knowlton, 2010). When entry fees are reinvested in the MPA they can support improved management capacity. Adequate staff and budgetary capacity for MPA management improves outcomes for fish biomass (Gill et al., 2017) and the reinvestment of entry fees into park management improves outcomes for coral cover (Hargreaves-Allen et al., 2017).

Revenue from tourism is affected by social and economic changes at the national and international scale (Cumming et al., 2015). Protected areas financed by tourism are vulnerable to disruptions of tourism, such as geopolitical conflict and epidemics (Spenceley et al., 2021). For example, Tanzania's national parks rely on tourism for much of their funding, but this funding has declined dramatically during economic

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recessions (Kideghesho and Msuya, 2012). Most recently, funds from nature-based tourism have declined globally during the COVID-19 pandemic (estimated international tourism was down by 72 % in the first 10 months of 2020 United Nations World Tourism Organisation, 2020). This decline in tourism has dramatically impacted many coastal economies, including those near to MPAs and has ongoing impacts as businesses close, international flights are cancelled and staff find new jobs. For instance, many MPAs had declines in budget because they lost tourism income, but only in some cases did government or private funds step in the fill the funding gap. Declines in budgets caused losses of staff employed to manage the MPAs (Phua et al., 2021). Thus, an understanding of the relationships between entry fees, how the income is spent, and its outcomes, are important to inform the design of financial management plans for MPAs to be sustainable in the face of economic shocks.

There are a range of mechanisms through which tourism can affect the ecological outcomes of MPAs, making it difficult to isolate the effect of entry fees specifically. Increasing tourism is often justified on the assumption that developing sustainable livelihoods linked to biodiversity conservation will create a feedback that further promotes conservation (Salafsky and Wollenberg, 2000). For example, alternative livelihoods from tourism can reduce fishing pressure around MPAs (Lopes et al., 2015) and the new jobs can bolster community support for the MPA, which may increase MPA rule compliance and reporting of poaching (Bergseth et al., 2018; Oracion et al., 2005). More broadly, MPAs often have goals relating to education of visitors (including tourists) and they can raise awareness of environmental issues, which ultimately also contributes to social and political support for conservation (Hargreaves-Allen et al., 2017). MPA management may benefit from tourism operators and tourists contributing to surveillance for enforcement of MPA rules and ecological monitoring (e.g. citizen science). For example, the increase in fish biomass in the MPA in Cabo Pulmo, Mexico is partly attributed to ecotourism operators who contributed to MPA management (Aburto-Oropeza et al., 2011). Tourism jobs have also played a significant role in the positive performance of the Raja Ampat MPA network by providing income to park management through entry fees as well as supporting local economies (Purwanto et al., 2021). Support to local economies can improve community perception of MPAs and potentially reduce poaching (Purwanto et al., 2021). Tourism can also have significant negative impacts on the ecological outcomes in MPAs. Visitors to MPAs can hinder ecological conservation by damaging habitats, driving ecologically unsound coastal development, promoting increased fishing pressure to feed tourists local seafood, or negatively disrupting social structures (Lopes et al., 2015; Suchley and Alvarez-Filip, 2018; Canty, 2007; Basurto et al., 2016).

Despite the case-studies linking tourism to the ecological outcomes of MPAs, little is known about how tourism supports financial security and subsequently MPA performance. Entry fees are not always reinvested back into park management, but where they are reinvested we would expect them to improve MPA outcomes. Moreover, there are multiple pathways for reinvested entry fees to facilitate MPA management. For example, entry fees could support hiring and training of staff and improve effective management activities like enforcement. Entry fees could also enhance outreach activities by funding infrastructure and education programs. Outreach activities then benefits ecological outcomes by improving community participation in monitoring and enforcement (Robert et al., 2022). The loss of entry fees has negative consequences for management capacity and the employment of park staff. For example, many MPAs including Kanamai-Mtwapa Co-Management Area in Kenya, Tun Mustapha Park, Sabah in Malaysia and the Great Barrier Reef Marine Park in Australia, have reported increases in illegal fishing stemming from declines in the tourism economy (Phua et al., 2021). These multiple pathways of influence mean an important question is what types of management activities entry fees support.

Here we assess how income from entry fees affects ecological outcomes and MPA management. First, we use a global survey of reef fish biomass in MPAs where no fishing (no-take) or some fishing (multiple-use) was allowed (the Reef Life Survey; Edgar and Stuart-Smith, 2014). We ask if park entry fees from visitors associated with higher fish biomass in MPAs (Aim 1). Increasing fish biomass is a primary ecological goal of many MPAs, particularly those that are no-take zones (though we note that MPA goals are usually much broader than just fish biomass, Hargreaves-Allen et al., 2017). We expected that entry fees would improve higher fish biomass, because funding for effective management improves the ecological outcomes of MPAs (Gill et al., 2017).

Second, we aimed to generate further hypotheses for how reinvestment of MPA entry fees relates to budget health, staff capacity, and community engagement (Aim 2). We use a global database of protected area management assessments, the Management Effectiveness Tracking Tool (METT, Coad et al., 2015) and tested hypotheses for how entry fees and the level of reinvestment relate to management effectiveness with structural equation models (SEM, Shipley, 2016). We hypothesized relationships among three latent (unmeasured) variables relating to management effectiveness: budget health, staff capacity and outreach capacity. We hypothesized that budget health is correlated with staff capacity because greater budgets help employ more staff. Moreover, staff can also do activities that increase the budget, such as advocacy and fundraising or managing entry fees. Staff capacity and budget health were proposed to support outreach activities (including engagement with local communities, tourism and commercial operators; education and awareness programs, visitor facilities). We included a correlation between security of budget and current budget because parks with secure budgets are more likely to have a greater current budget. Finally, we proposed entry fees were a driver of budget health and that this relationship would become stronger with greater levels of fee reinvestment.

2. Methods

2.1. Fish biomass data – Reef Life Survey

We used the data in Edgar et al. (2014) from the Reef Life Survey (RLS) to ask how tourist entry fees and tourism intensity relate to fish biomass recorded by divers on standardized surveys of shallow reefs in 86 MPAs (Aim 1). For biomass, we used the ‘total biomass of fish longer than 20 cm’ (henceforth ‘biomass’) indicator because it is a sensitive indicator of fishing pressure that is responsive to MPA management, and independent of confounding temperature effects (Stuart-Smith et al., 2017). This quantitative analysis was conducted independent of the analysis of budget health and community engagement, because there was insufficient overlap between MPAs in the METT database and those surveyed by Edgar et al. (2014). For each survey site we used one year of data only. If multiple years were available, we used the year closest to 2015, because this is when we had the most fish survey data.

We scored two tourism indicators for each MPA in the RLS dataset. First, we conducted a web search for all MPAs in the database to identify if they have an entry fee or not (Fig. 1, see Table S1 for sources). Entry fee was included in the analysis as a binary variable (yes/no). We then scored each MPA on a 1–5 scale for tourism intensity, where 1 means rarely visited (e.g. Coral Sea MPA, Australia) and 5 means high intensity (e.g. MPAs around Sydney Australia) (Table S1). The scoring was completed by a subset of this study’s authors (GE, NA-D, RS) who between them have visited all the MPAs in the RLS database. Ideally, we would have detailed information on park budgets so we could also assess whether entry fees are reinvested in park management and how much of the budget they meet. This information was not publicly available for most of the parks we reviewed, and indeed managers may be unwilling to share financial details (Bohorquez et al., 2019). We therefore did not include reinvestment as a variable in the analysis for aim 1, however, we have addressed reinvestment question under aim 2.

We used a four-step modelling process to evaluate the effects of MPAs and the tourism indicator on biomass. Multiple steps were necessary so we could establish the effect of MPAs on fish biomass against the counterfactual of no change in fish biomass ("biomass gain", also known as the additionality), and then determine the effect of entry fees on biomass gain. We used spatial comparisons to identify the biomass gain because data on biomass gain before and after MPA establishment were not available for most MPAs. First, we developed a predictive model of biomass outside of MPAs by statistically modelling biomass only at the 1657 sites outside of MPAs (supplementary methods, following Edgar et al., 2014).

In the second stage of the analysis, we estimated the gain in fish biomass attributable to each MPA by comparing the observed MPA biomass to the counterfactual predictions without the MPA. We first used the model of the relationship between fish biomass and environmental conditions at non-MPA sites to predict the counterfactual for the 1014 surveys within 86 unique MPAs. We then subtracted the predicted counterfactual from the observed $\log_{10}$ biomass at each MPA site to calculate a biomass gain statistic (a $\log_{10}$ ratio), which represents the predicted effect of the MPA on fish biomass. This step assumes that the counterfactual model is an adequate representation of fish biomass inside the MPAs in the absence of protection (i.e., if no MPA existed).

In the third step of the modelling, we applied structural causal modelling (Pearl, 2009) to develop tests of the effect of tourism and entry fees on gain in fish biomass. Structural causal modelling is new to ecology but well established in other fields (for ecological applications see: Arif and MacNeil, 2022; for a complete treatment of causal modelling see: Pearl, 2009). In structural causal modelling we first draw diagrams of hypothesized causal processes. The diagrams include the variables as nodes and hypothesized causal relationships as directed arrows. We proposed three causal diagrams relating entry fees, NEOLI ('no-take, well enforced, old, large and isolated') management score, and tourism to fish biomass gain (Fig. 2). The NEOLI score is a count between 0 and 5 of the number of the key features an MPA has (Edgar et al., 2014). We followed previous studies in our approach to using the NEOLI score, rather than modelling effects of its individual features, because the data had insufficient power to study the features separately.

In the first model (A) gain in fish biomass was directly caused by entry fees, tourism intensity and the NEOLI features. We also hypothesized that entry fees were more likely in areas with greater tourism. In the second model (B) we additionally hypothesized that entry fees were more likely to have been implemented when fish biomass was higher, because of their potential to attract tourists (e.g. Dixon et al., 2000). Note we did not have data for fish biomass before the implementation of entry fees, however, we can still estimate the effect of our target causal variables (i.e., NEOLI, park entry fees and tourism intensity) if fish biomass is not in its adjustment set. In the third model (C) we added unmeasured factors that drive both increased NEOLI features and entry fees. These factors could include the organization and capacity to enhance MPA management and implement fees.

We then apply the logic of causal calculus to determine 'adjustment sets' for statistical tests of causation. Adjustment sets are the conditioning variables required to be included to prevent confounding the test of a target variable (i.e. NEOLI, tourism intensity or entry fee) on fish biomass gains. For each model we determined the adjustment sets by applying the backdoor criterion (Pearl, 2009). We also analysed the paths between each target variable and fish biomass gains, paying particular attention to paths that included a collider variable. Conditioning on colliders can induce spurious correlations (Pearl, 2009). The causal models were plotted with the ggdag package (Barrett, 2022), the adjustment sets were determined with the daggity package (Textor et al., 2016) in R.

In the fourth step we tested the proposed causal models. Structural causal modelling allows us to use any statistical inference tool to test the strength of effects hypothesized in the diagrams. We fitted a Gaussian GAMM with an identity link function to test for the effects of MPA attributes (the NEOLI score: no-take, enforced, old, large, isolated, Edgar et al., 2014), the tourism intensity score, and the binary factor for an MPA entry fee (Table S4) on fish biomass gain. We did include an interaction between entry fee and the NEOLI score, because MPA fees may be more beneficial in MPAs with higher NEOLI scores. This GAMM also included a random intercept for the MPA, which accounted for unmeasured management, human pressure and environmental factors that may cause variation in fish biomass gains by MPA. We checked model assumptions were met, including that there was no residual spatial autocorrelation (Figs. S3 & S4).

In all steps the GAMMs were fitted using maximum likelihood method of smoothness selection with the mgcv package (Wood, 2017) in R (R Core Team, 2021) and we used stepwise removals based on the Akaike Information Criterion (AIC) to select the best model (Tables S2 &

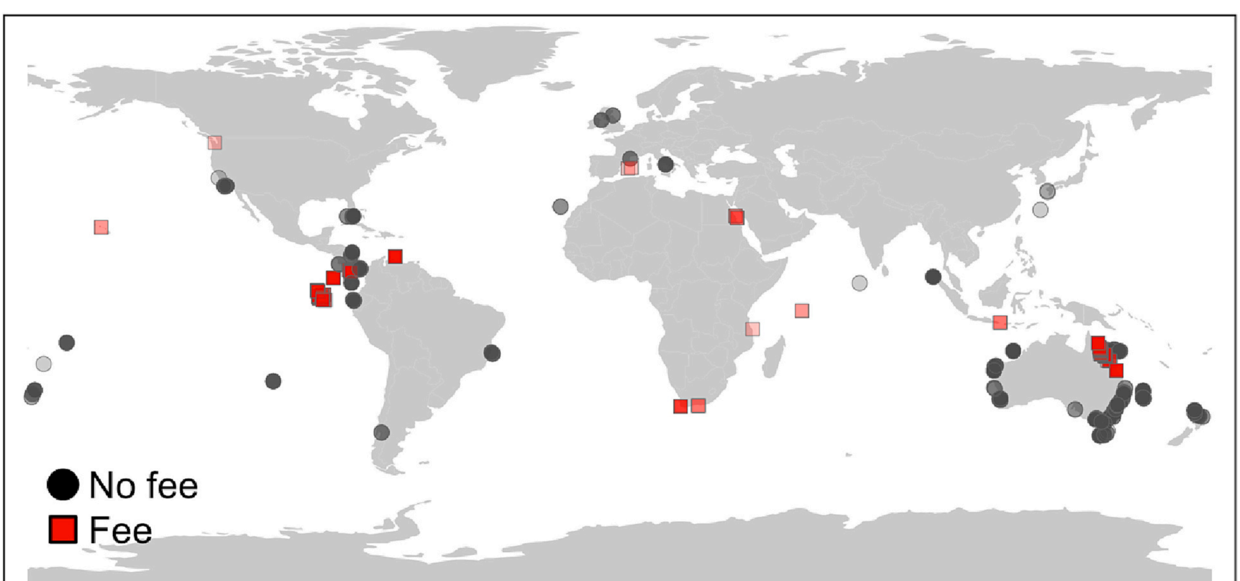

Fig. 1. Locations of RLS survey sites and whether or not they have an entry fee. Individual points for MPAs are opaque, so darker shading indicates regions with multiple MPAs.

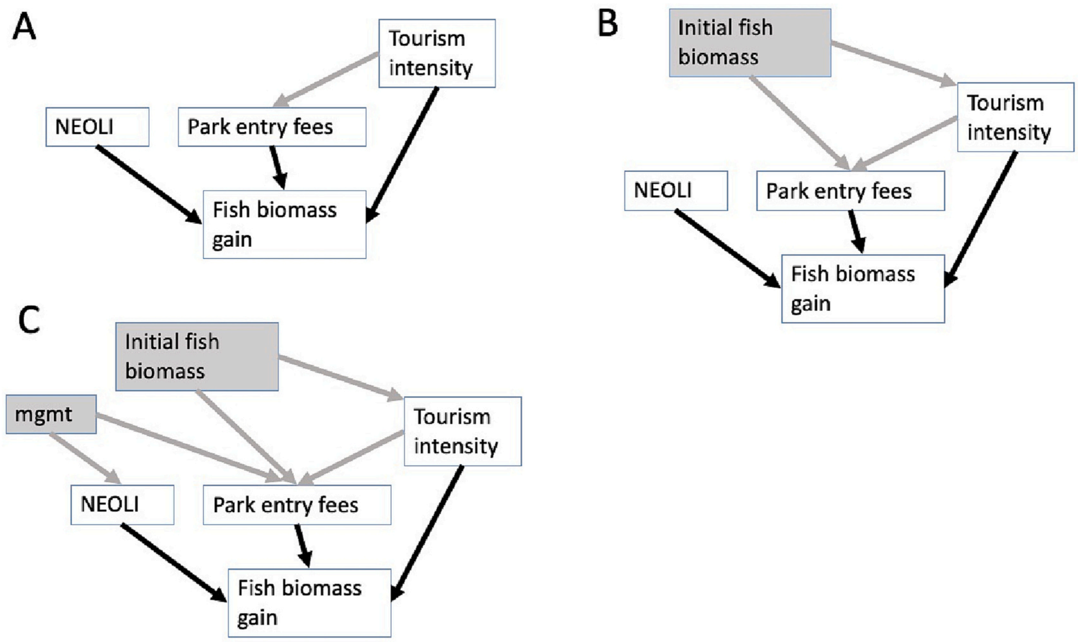

Fig. 2. Causal diagrams representing hypotheses for the causal relationships between three target variables (entry fees, NEOLI, and tourism intensity) and fish biomass gain. (A) simple model; (B) model with effect of initial fish biomass before entry fee implementation; (C) model with unmeasured effect of good management ('mgmt') on both fees and NEOLI. Black arrows are the causal effects we tested here, grey arrows were not tested. Shaded boxes indicate variables for which we do not have data.

S4). We undertook residual analyses to ensure the model had no residual spatial autocorrelation, and that the residuals were not heteroscedastic (Figs. S1 & S2). The effect sizes of NEOLI and tourism variables were evaluated using empirical Bayesian simulation to calculate the two-sided probability of a change in biomass and effect sizes with Bayesian credible intervals (Wood, 2017). We also estimated the effect of increasing from NEOLI 1 to NEOLI 5, and comparing MPAs with no fee to those with fees (supplemental methods).

2.2. Structural equation models of management effectiveness

Next, we ask how entry fees relate to management effectiveness, budgets, staff and activities (Aim 2). We conducted analysis on the METT database, a self-assessment tool that includes data from protected area management effectiveness surveys conducted by MPA managers and other stakeholders (Gill et al., 2017; Coad et al., 2015). We analysed 10 questions relating entry fees, budgets, staff and outreach activities (Table S5). Each question is scored on a 0–3 scale where 0 indicate that

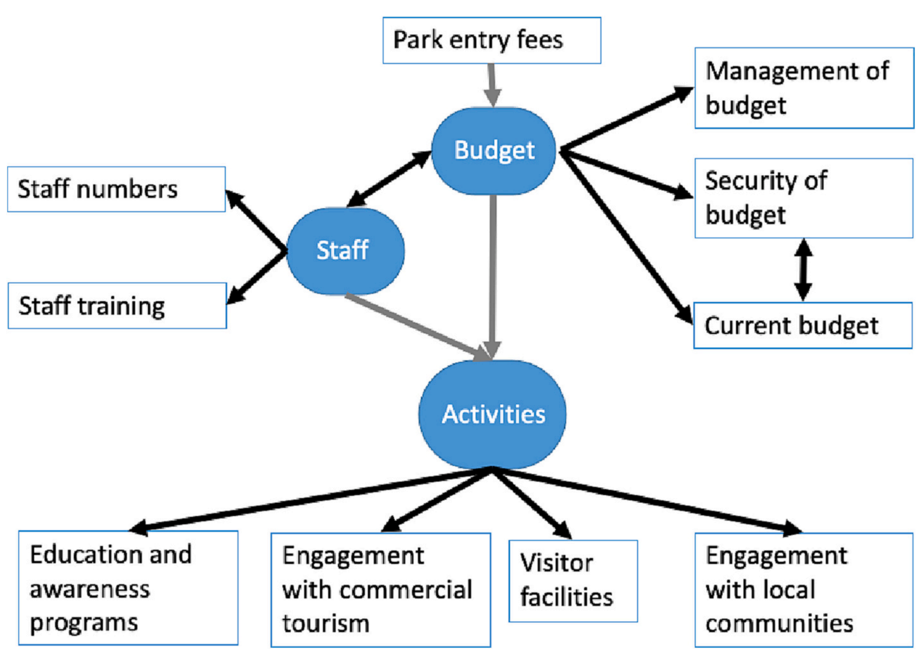

Fig. 3. Hypothesized model relating reinvestment of entry fees to management outcomes. Unidirectional arrows represent causal relationships, double headed arrows represented correlations, boxes are observed variables (METT survey questions), ovals are latent variables. Grey arrows represent connections that we removed one at a time to test the full model against a simplified nested model.

the specific element is entirely absent or inadequate and 3 that the element is fully implemented or adequate. Analysing these questions allowed us to infer the effect of entry fees, and whether greater levels of entry fee reinvestment were associated with greater budget security. Under the entry fee question, a score of 0 indicates no fee collected, 1 indicates a fee is collected but makes no contribution to the MPA, 2 indicates it makes some contribution and 3 indicates it makes a substantial contribution. Similarly, under the 'Current budget' question there is scale 0–3 that scales from no budget to a budget that fully meets the MPA's needs. There were 214 MPAs with sufficient data in the METT to be analysed here (supplemental methods).

The SEM included observed variables (the METT questions) and latent variables (Fig. 3). Latent variables are concepts that represent cross-correlations among measured variables. In the first attempt at a SEM it is common to find the model is insufficient (Grace et al., 2010), which was the case in our modelling. We sequentially added relationships and retested the model, starting with the relationship that had the highest modification index (Shipley, 2016). The modification index identifies where adding residual correlations could enhance model fit. This process of updating the models meant our results should be interpreted as an exploratory approach to generate hypotheses, not an inferential test of hypotheses as initially intended (Shipley, 2016; Grace et al., 2010).

The SEMs were fitted with the LAVAAN software (Rosseel, 2012), in the R programming language (R Core Team, 2021). The survey questions were treated as ordinal categorical responses, except for entry fee which was a driver of budget health. Budget health was assumed linearly related to the score of the entry fee question, because we hypothesized parks with greater reinvestment of entry fees (going from score 1 to score 3) would have greater budget health. Models were fit with the WLSMV estimator (Rosseel, 2012), and the variances of the latent variables were standardized to enable comparison of path strengths across all observed variables. Path coefficients are standardized coefficients that represent the relative strength of relationships in the model. Overall fit of the full model was evaluated with the chi-square statistic, where a p-value > 0.05 meant the model adequately represented all correlations among survey responses and $p < 0.05$ indicates that not all correlations in the responses are captured by the model.

We interpreted possible causal relationships in the modified model by testing it against three nested sub-models that differed by one connection (grey arrows in Fig. 3). The model comparisons were tested with likelihood ratio tests (Gonzalez and Griffin, 2001). These sub-models included models where we removed the effect of: entry fees on budget health, budget health on outreach activities and staff capacity on outreach activities. We could not test a sub-model that lacked a correlation between budget health and staff capacity, because the model without that correlation was not identified (see rules for SEM identification Shipley, 2016). Finally, we discussed the best fit model in terms of the path coefficients and their standard errors.

3. Results

3.1. Fish biomass data — Reef Life Survey

All causal diagrams required the effect of entry fee on fish biomass gain should be tested while conditioning on tourism intensity (Table S3). NEOLI should also be conditioned on under model C (Fig. 2C). A model conditioning on entry fee and tourism intensity was also suitable for testing the effect of NEOLI on fish biomass gain. NEOLI and entry fees were never colliders for each other, therefore we proceeded with a single GAMM to test the interacting entry fee and NEOLI effects.

No conditioning variables were required to test the direct effect of tourism intensity on fish biomass gain under model A (Fig. 2A). Casual diagrams B and C both required initial fish biomass in the adjustment set (Fig. 2). Further, entry fee was a collider for test of tourism intensity on fish biomass gain. Therefore, our test of tourism intensity is only valid for model A.

The model with the NEOLI and entry fee interaction and conditioning on tourism intensity explained 32 % of the model's null deviance. There was slightly more evidence for a model with an interaction between NEOLI score and presence of an entry fee than for an additive only model (AIC of 1855 vs 1866, Table S4). The NEOLI score had a strong effect on the biomass gain for parks without entry fees, where the biomass gain was 5.0 times higher in areas with a NEOLI score of 5 when compared with a NEOLI score of 1 (1.94–14.22 95 % C.I.s, Fig. 4A). The probability that the biomass was greater with NEOLI=5 than NEOLI=1 was equal to 1.

Parks with entry fees had higher biomass gains at NEOLI scores 1 and 2 than parks without entry fees (Fig. 4A, $p = 0.99$ and $p = 0.99$ respectively, 4.4 times higher at NEOLI=1 and 2.6 times higher at NEOLI=2). This result was counter to our hypothesis that entry fees would have a greater effect for parks with higher NEOLI scores. At NEOLI scores 3 and above there was no difference in biomass gain between parks with and without entry fees (at NEOLI 3 a 1.46 times difference with 95 % C.I.s of 0.84–2.76). This interactive effect also meant that biomass gains in parks with entry fees were similar for all NEOLI scores (Fig. 4A)

There was a decline in the biomass gain statistic with increasing tourism, but evidence for this effect was very weak (probability = 0.84, with a 0.72 times change from low to high tourism and 95 % C.I.s of 0.40–1.36 Fig. 4C). Note that by conditioning on entry fee we excluded its indirect effect on fish biomass and are estimating the strength of only the direct effect of tourism on fish biomass gain.

3.2. Structural equation models of management effectiveness

The full model had a significant p-value meaning that it was not adequate to explain correlations among the METT questions (model chi-square = 111, $p < 0.001$). We therefore sequentially added two more relationships to achieve a model with $p > 0.05$. First, we added a correlation between staff capacity and entry fees, but the model was still significant (model chi-square = 64, $p < 0.001$), we then added a correlation between visitor facilities and engagement with commercial tourism operators (model chi-square = 41, $p = 0.059$) (Fig. 5).

Next, we sequentially tested the three sub-models for the relationships among entry fees and the latent variables. The tests confirmed that entry fees and greater reinvestment of entry fees were drivers of budget health (path coefficient = 0.68, $p < 0.001$). The latent variable for outreach activities was positively affected by budget health, but the relationship was not significant (path coefficient of 0.27, $p = 0.69$). There was a significant positive effect of the staff latent variable on the outreach activities latent variable (1.83, $p = 0.01$). Overall, this model suggests that reinvested entry fees are a driver of budget health, budgets are correlated with staff capacity, and staff capacity is the primary driver of outreach activities. For the final version of the model, all observed variables were strongly related to their respective latent variables (Table S6, path coefficients are $>2\times$ their respective S.E.s).

4. Discussion

We found evidence that MPAs with entry fees had a gain in fish biomass that was 4.4 times the gain compared to MPAs with no entry fees, but only at low NEOLI scores. This effect occurred over and above the existing, previously documented benefits of MPAs that have the five key features of: no-take, well enforced, large, old and isolated (Edgar et al., 2014). The interaction between entry fees and NEOLI suggested that entry fees were only positively correlated with biomass gain at low NEOLI scores, which was counter to our hypothesis. This result suggests that MPAs with high NEOLI scores have sufficient funding from other sources to protect fish, such as from government. Alternatively, it could suggest that funding from entry fees in parks with high NEOLI scores is not spent on activities that are beneficial for fish biomass, or the funding

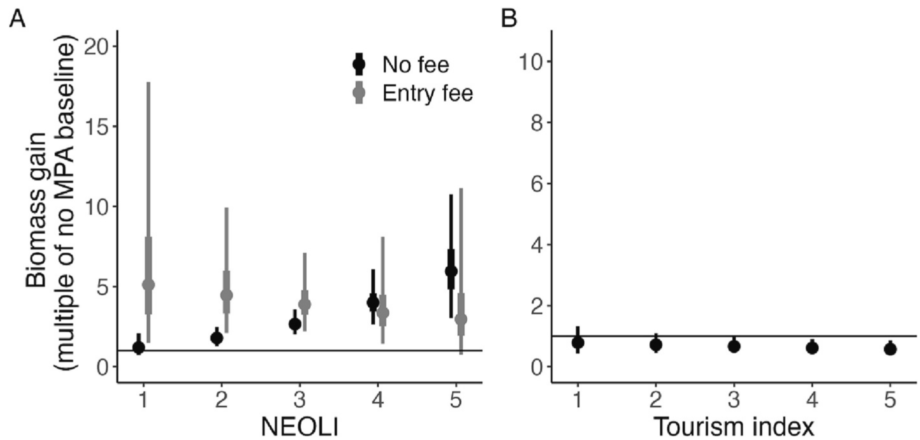

Fig. 4. Modelled effects of (A) 'NEOLI' (No-take, well enforced, old, large and isolated) for MPAs with no fee, and fee type for NEOLI = 1 and (B) Tourism Index for NEOLI = 1, on fish biomass gains relative to a no MPA baseline. Points show median estimate, thick bars show 75 % credible intervals, thin bars show 95 % credible intervals. Solid horizontal line shows baseline of no difference from no MPA.

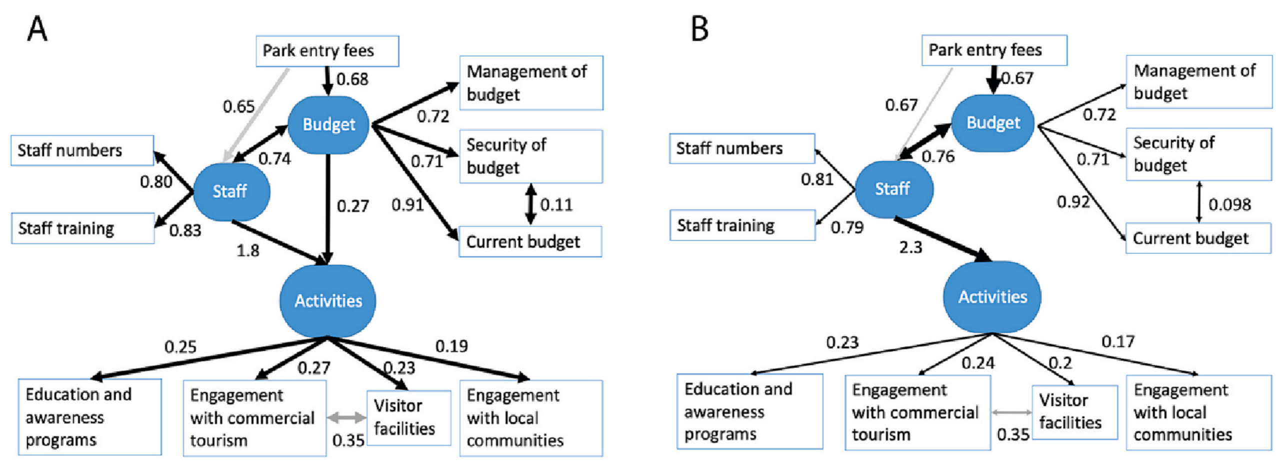

Fig. 5. The final modified structural equation model with latent states for budget, staff, and activities (A) and the best fit nested sub-model (B). Observed variables are in square boxes, latent variables in ovals. Unidirectional arrows show hypothesized causal effects, double-headed arrows show correlations. Numbers on arrows indicate path coefficients for unidirectional arrows and correlation coefficients for bidirectional arrows. Larger coefficients suggest a stronger effect. Additional modifications are adding two residual correlations (grey arrows). In (B) thick arrows indicate relationships that were tested with nested sub-models.

is redirected to other institutions.

The model of management effectiveness suggested that reinvested entry fees supported outreach activities, budget health and staff capacity. Budget health was correlated with staff capacity, but the direction of the relationships was unclear. The correlation may represent a positive feedback, whereby better budgets support greater staff capacity, and staff capacity benefits budget health. Staff capacity, in turn, was an important driver of outreach activities, including engagement with local communities, commercial tourism operators, and education programs. The benefit of entry fees to staff capacity could improve park management in multiple ways. Sufficient budgets could support staff to better enforce park rules (Gill et al., 2017). Outreach activities may benefit fish biomass by raising support for the MPA with local park users and educating users about park rules, which prevents accidental violation of the rules (Turner et al., 2016). Outreach can also encourage user participation in management activities, such as park users reporting poaching to authorities (Bergseth et al., 2018; Oracion et al., 2005). Together, these results suggest that park entry fees that are reinvested in park management may help improve fish biomass outcomes by improving staff numbers and training. The specific ways that improving staff benefits fish biomass, either via enforcement, outreach activities or other management activities, need further investigation.

Future studies of MPA entry fees could be improved by having both biological and management effectiveness data for the same set of MPAs. In our analysis there was little overlap of MPAs between the METT and RLS datasets. Overlap in the datasets would let us draw stronger conclusions about the casual mechanisms linking entry fees to gains in fish biomass. Our test for the effects of entry fees on fish biomass was supported by three alternative causal models. Our causal models accounted for the possibility that managers may select MPAs with higher fish biomass for implementation of entry fees. Our results therefore add greater resolution to earlier results that more effective management benefits the ecological outcomes of MPAs (Gill et al., 2017; Aburto-Oropeza et al., 2011; Giakoumi et al., 2018; Ban et al., 2017). Future work should look mechanisms linking entry fees to gains in fish biomass. For instance, it would be helpful to understand how specific NEOLI factors (like no-take status) interact with entry fees to influence fish biomass. A structural equation modelling approach informed with temporal data on the specifics of park budgets, including the activities that entry fees support, could be used to determine how entry fees interact with other factors to influence fish biomass.

We could not draw conclusive results about the effect of tourism intensity and gains in fish biomass. Two of the causal models suggested that the tourism intensity effect may be confounded if pre-MPA biomass was not controlled for; data we did not have. A plausible explanation for why there was no relationship is that the net effect of tourism is confounded by positive and negative effects of tourism on fish biomass. Refining the tourism intensity index to include multiple factors, for instance by including measures of tourism related to coastal pollution (Suchley and Alvarez-Filip, 2018), fish feeding by tourists, fishing by tourists, and demand for reef fish by tourists (Wabnitz et al., 2018), could enhance the power of our analysis to detect a tourism effect at individual MPA sites. Alternatively, assessing whether other taxa that are more vulnerable to physical and environmental stress (e.g., sessile invertebrates) may support the hypothesis that tourism intensity impacts MPA performance.

MPA outcomes more broadly than fish biomass also need to be assessed. MPAs typically have multiple objectives that encompass social, ecological, economic, and cultural outcomes (Fox et al., 2012; Giakoumi et al., 2018). MPAs in low income nations, where the METT database is biased to, often have objectives more heavily focused on fisheries management. Indeed, fish biomass gains may not be the primary objective of many of the MPAs in our analyses and the income from entry fees may support other outcomes, like tourism revenue, over directly improving fish biomass. There is need therefore to create standardized databases of how MPAs are funded (Bohorquez et al., 2019) and finances allocated, and then quantify how MPA funding relates to a broader range of benefits (Hargreaves-Allen et al., 2017).

Information on MPA finances could be used to study how budget allocation for MPAs impact their effectiveness. For instance, some MPA entry fees are not returned to park management, and when entry fees are returned to the park, rarely are they sufficient to cover all park management costs (Peters and Hawkins, 2009; Gelcich et al., 2013). Further, in low-income countries there is a risk that entry fees exclude locals who have lower purchasing power than international tourists so, many MPAs have different or no fees for locals. It is unclear how these different systems affect the ecological outcomes for MPAs. Unfortunately, we could not obtain sufficient information on how entry fee pricing varies by different user groups to conduct a formal analysis. This could be an important type of information to include in databases of how MPAs are funded (Bohorquez et al., 2019).

The METT database has caveats that may have affected our results. For example, it is biased towards nations where MPAs were supported with donor funding (Coad et al., 2015). MPAs operating in wealthy nations may receive greater direct financial support from government, so the role of entry fees may be different to what we have inferred here. Greater access to transparent information about MPA funding sources would be required to explore this caveat (Bohorquez et al., 2019). Notably, the METT database does not capture information on governance, thus the management effectiveness variables could be explained by an unobserved variable that co-drives many management outcomes, such as institutional leadership or even the influence of highly motivated individuals on park management (Purwanto et al., 2021; Coad et al., 2015; Geldmann et al., 2015). Testing these ideas in models will require in-depth assessment of relationships between other attributes of management, governance, and context (Hargreaves-Allen et al., 2017; Fox et al., 2012).

We found evidence that entry fees support budget health and thus contribute to MPA management. Additionally, we found a link between engaging with commercial tourism operators and visitor facilities, suggesting that investment in visitor facilities could enhance commercial opportunities and therefore, financing. We suggest that entry fees can be implemented to support the ecological outcomes of MPAs, where they align with the broader social context of the MPA. But, the benefits of entry fees also come with risks, because tourism shortfalls caused by economic shocks will affect MPA management. The decision to implement entry fees should also consider a broader context than just the ecological benefits, equity of access is also an important consideration, as is the moral stance of stakeholders on paying to access an open-access resource (Peters and Hawkins, 2009). Future studies are needed to compare MPA ecological performance pre- and post-implementation of entry fees to better identify their effects on MPA management.

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CRediT authorship contribution statement

Chris Brown: Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Supervision, Visualization, Writing – original draft, Writing – review & editing. **Gabby N. Ahmadia:** Conceptualization, Writing – review & editing. **Dominic A. Andradi-Brown:** Conceptualization, Writing – review & editing. **Nur Arafeh-Dalmau:** Conceptualization, Writing – review & editing, Investigation. **Christina A. Buelow:** Conceptualization, Writing – review & editing, Investigation, Formal analysis, Methodology. **Max D. Campbell:** Conceptualization, Writing – review & editing, Methodology, Formal analysis. **Graham J. Edgar:** Conceptualization, Writing – review & editing, Investigation. **Jonas Geldmann:** Conceptualization, Writing – review & editing, Investigation. **David Gill:** Conceptualization, Writing – review & editing, Investigation, Formal analysis. **Rick D. Stuart-Smith:** Conceptualization, Writing – review & editing, Investigation.

Declaration of competing interest

The authors have no conflict of interest to declare.

Data availability

Data available bia public repo.

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