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The income requirements of marine protected areas

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Abstract

Given the growing impact of human activities on the sea, managers are increasingly turning to marine protected areas (MPAs) to protect marine habitats and species. Many MPAs have been unsuccessful, however, and lack of income has been identified as a primary reason for failure. In this study, data from a global survey of 79 MPAs in 36 countries were analysed and attempts made to construct predictive models to determine the income requirements of any given MPA. Statistical tests were used to uncover possible patterns and relationships in the data, with two basic approaches. In the first of these, an attempt was made to build an explanatory ‘‘bottom–up’’ model of the cost structures that might be required to pursue various management activities. This proved difficult in practice owing to the very broad range of applicable data, spanning many orders of magnitude. In the second approach, a ‘‘top–down’’ regression model was constructed using logarithms of the base data, in order to address the breadth of the data ranges. This approach suggested that MPA size and visitor numbers together explained 46% of the minimum income requirements ($p < 0.001$), with area being the slightly more influential factor. The significance of area to income requirements was of little surprise, given its profile in the literature. However, the relationship between visitors and income requirements might go some way to explaining why northern hemisphere MPAs with apparently high incomes still claim to be under-funded. The relationship between running costs and visitor numbers has important implications not only in determining a realistic level of funding for MPAs, but also in assessing from where funding might be obtained. Since a substantial proportion of the income of many MPAs appears to be utilized for amenity purposes, a case may be made for funds to be provided from the typically better resourced government social and educational budgets as well as environmental budgets. Similarly visitor fees, already an important source of funding for some MPAs, might have a broader role to play in how MPAs are financed in the future.

1. Introduction

Oceans provide an extensive range of benefits to human populations [1,2], but threats to their continued provision are considerable. No other resource has in recent times been so touched by what Hardin [3] called the ‘‘tragedy of the commons’’ – a common resource, over-exploited by all parties in the face of little or no accountability. Foremost amongst the methods currently being proposed to address the degradation caused by overuse and overexploitation are marine protected areas (MPAs) – places in the sea designed to protect the marine environment from the growing tide of human

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impact. MPAs may have many benefits including the protection and rebuilding of commercial fish populations [4], prevention of stock collapses and insurance against management failure in fishing grounds [5]. They also protect vulnerable and important habitats and species [6] and enable opportunities for tourism, recreation and education [7,8].

Although well over 1300 MPAs exist, these currently cover less than 1% of the oceans in area and their management is of highly variable quality [9]. A number of surveys have assessed the adequacy of MPA management (e.g. Refs. [10–14]). The most extensive [10] found that nearly a third of the global sample of MPAs surveyed had a low level of management and generally failed to meet their objectives. More recent studies continue to demonstrate underperformance. Pet-Soede [15] estimated that less than 20% of Indonesian MPAs were functional while Mora et al. [16] state that although 40 or so MPAs are created each year to protect coral reefs, they are rarely managed or enforced adequately postestablishment.

The 2002 World Summit on Sustainable Development in Johannesburg paved the way for a significant increase in the global coverage of MPAs, with an ambition to create a worldwide network by 2012 [17]. In order for these new protected areas – and indeed existing MPAs – to be effective, we require a comprehensive understanding of the variables that determine their success. An extensive body of research suggests that access to sufficient resources, including income, is key [18–20]. Although lack of funds is cited repeatedly as a cause of MPA failure by numerous commentators, adequacy of funding for start-up, recurrent, and/or capital costs is rarely given as the only success factor. Funding is seen as one variable among many – a necessary but not a sufficient condition for success. However, there appear to be very few estimates as to how effective MPA management costs.

In the first instance, very little information is available on what is currently spent on MPAs. Wilkie et al. [21] suggest that governments are often reluctant to disclose funding information in case it is used against them (i.e. it is shown to be insufficient) and that donors and NGOs consider such information proprietary. Government expenditures on protected areas are generally not given in international financial statistics. What information exists tends to be unpublished "grey" literature, produced by foreign aid agencies and development banks for example, that generally has limited availability and is not systematically catalogued.

The most comprehensive estimate of protected area funding requirements was produced by James et al. [22] for terrestrial protected areas only. This study found an enormous range in the adequacy of funding between different world regions.

Broad estimates of protected area funding requirements, like those above, give general guidance on costs but are only of limited use to policy makers involved in allocating MPA budgets. Existing and future MPAs have a great range of objectives. It is highly unlikely that their income requirements will be uniform.

Several authors suggest what they regard to be the key drivers of protected area income requirements, including elements of the biological, social and cultural environment (i.e. context) of the protected area [23]. This context sets the level and nature of inputs (including funds) required to manage that area successfully, be it marine or terrestrial. Hockings et al. [24] divided factors determining management requirements between intrinsic (internal) features of the protected area (e.g. area and management objectives) and external drivers (e.g. visitor numbers and legal obligations).

A number of authors have attempted to establish what factors, if any, are the most significant in determining income requirements. For example, James et al. [22] found that the costs of smaller protected areas were higher than those of larger areas on a per square kilometre basis. Balmford et al. [25] found that costs of effective terrestrial conservation increase with the extent of local development and population density, the size of the protected area and a number of economic variables including per capita GNP. Similarly, the Balmford et al. [26] study on the cost of a global MPA network found that annual MPA running costs were higher in smaller protected areas that were closer to coasts and in high-cost, developed countries.

All of these previous studies have taken a broad-brush, or "top–down" approach to MPA funding, largely considering contextual variables external to the individual MPAs. The aim of this study is to provide a more detailed analysis, considering the financial requirements of individual MPAs, based upon both external and internal determining factors to the protected areas. The focus of the analysis is on ongoing management costs.

2. Methods

In order to assess funding requirements, a questionnaire was developed and sent to MPAs around the world. The intention was to establish a broad operational and financial profile of the MPAs surveyed to illuminate specific funding requirements.

Approximately 500 questionnaires were distributed between November 2001 and May 2002 to those individuals responsible for each MPA identified. Individuals were targeted rather than managing agencies as it was felt that responses of the latter might be more "political" than those with "hands-on" management responsibility. The aim was to obtain a sizeable sample covering all types of MPAs in all parts of the world, capturing the full range of potential environmental, social and economic objectives from small protection-oriented units to large recreational areas.

The questionnaire was split into five categories of questions: respondent details, MPA details, income, spending patterns and future funding requirements. Details of the MPAs' finances were provided by the respondents in a range of currencies and for a range of financial years. In order to analyse this financial information it was necessary to standardise it into data that could be compared across all replies. This involved conversion into a common currency (US dollars) and calendarisation towards a fiscal year ending December 2001.

The data were analysed using bivariate and multivariate methods to define the characteristics of the MPAs surveyed and to explore their relationships to the costs of management. Variables were put forward for testing where they might have some bearing on the financial profile of MPAs, and specifically funding requirements. The selection of variables used for the analysis reflected both the literature and a broader sense of what factors might be influential. The eight variables selected were MPA size (area in hectares), purpose, habitats or species protected, annual visitor numbers, geographical location, GNI per capita (gross national income per capita of the host country), zonation (extent to which all or part of the MPA is protected from fishing) and source of funds.

MPA size, purpose, habitat protected and visitor numbers were selected as variables based on the existing literature on protected area management. Whether the MPA has as an objective with the intention to benefit fisheries outside of the reserve was also included as a key MPA purpose. Geographical location and GNI per capita are standard biogeographical and economic considerations and have been shown in a number of existing surveys (e.g. Ref. [22]) to have an important bearing on current if not ideal income requirements. Zonation and source of funds are potentially influential factors which may determine income requirements but have received scant attention in the literature. In this analysis MPA zonation was categorised into two groups: protected areas that protect more than 5% of their area from fishing and those that have "no-take" areas of less than 5%. The 5% figure is arbitrary. Source of funds refers to the primary contributor of a protected area's funds.

Values for all of the variables were taken from questionnaire returns, with the exception of GNI per capita which was taken from the World Bank (2000) data.

The data were first explored using a bivariate analysis whereby each separate element of the responses was tested against the variables detailed above. A wide range of tests were used depending upon the nature of the inputs, i.e. whether it was categorical/nominal or interval/ratio, etc. To maximise the quality of the statistical output, parametric tests were used where possible, which in a number of cases involved a re-categorisation of the data. Multivariate techniques were then applied to see if income requirements were linked to particular types of MPA characteristics or regions.

3. Results

The survey produced responses from 79 MPAs in 36 countries. These replies were distributed across 14 of the 18 marine systems designated by the IUCN World Commission on Protected Areas. Hence they are broadly representative of marine ecosystems as a whole. Forty-two of the responses were from developed countries, predominantly in the northern hemisphere, while 37 were from developing, largely southern hemisphere countries.

Responses came from a wide range of MPAs in terms of size, visitor numbers and annual income, the values of each spanning many orders of magnitude. The smallest MPA covered just 10 ha while the largest was 13 million hectares. Annual visitor numbers ranged from zero for some MPAs to more than 100,000 for others. Annual income figures (discussed below) also covered an extensive range. The range of values for each variable was not bunched around any particular "average" figure but was relatively evenly distributed, on a logarithmic basis, across the whole range.

Fig. 1 illustrates the range of annual income reported by the MPAs surveyed. The mean income was approximately USD 750,000 per year while the median was nearly USD 250,000. Median income per hectare was USD 15 and median income per visitor was USD 19. While it might be tempting to use these figures as benchmarks for various calculations, the great breadth of the data means that these averages contain limited information. For example, 18 of the MPAs surveyed reported no income. In reality, the "average MPA" is not a helpful construct.

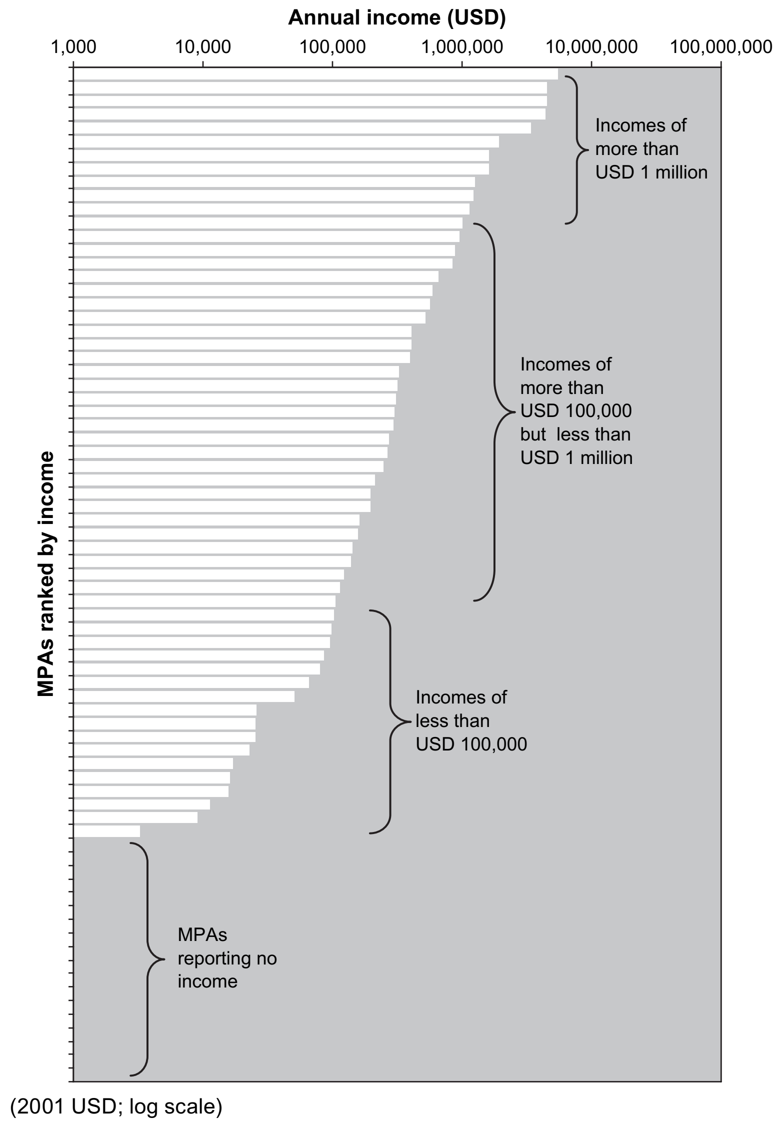

Fig. 1. Distribution of annual incomes across MPA sample.

Cluster analysis of the data showed that the MPAs in the sample could be categorised into three main groupings (see Table 1) defined by a range of characteristics such as their visitor numbers, purpose, income and spending patterns. The first grouping (Cluster A) comprised MPAs principally focused on fisheries and enforcement[1]. These were typically in poorer countries and had relatively low visitor numbers. The second, largest group (Cluster B) consisted of MPAs with a very wide range of purposes, from recreational to commercial – including benefit to fisheries. The final group (Cluster C) was the smallest and least well defined. These MPAs had a more restricted range of purposes than either Cluster A or Cluster B. In particular, they were less likely to allow either recreational or commercial fishing. Given the relatively low visitor numbers and significant occurrence of no-take areas, one might tentatively suggest that MPAs in Cluster C have more of a dedicated conservation bias than MPAs in the two other clusters. The differences between these three clusters were apparent even where characteristics such as size and habitat type might be similar.

[1] The survey allowed for correspondents to categorise their activities according to their own definitions, including a definition of enforcement.

Table 1
Characterisation of the MPAs by cluster analysis

	Cluster A	Cluster B	Cluster C
Region (% breakdown)	95 South, 5 North	50 South, 50 North	77 North, 23 South
Area (% breakdown)	USA = 11 Caribbean = 6 Indo-Pacific = 83	USA = 27 Europe = 18 Caribbean = 32 Indo-Pacific = 18 Australia/NZ = 5	USA = 31 Europe = 23 Caribbean = 8 Indo-Pacific = 15 Australia/NZ = 23
Funds (% breakdown)	Government = 47 Foreign entities = 47 Visitors = 6	Government = 80 Foreign entities = 10 Visitors = 10	Government = 80 Visitors = 20
GNI per capita (USD)	4656	16,534	25,641
Size (mean ha)	21,012	160,429	67,908
Visitor numbers (counts)	49,940	259,674	145,062
Coral (Y/N)	94	50	54
Benefit to fisheries (Y/N)	89	23	15
No-take zone > 5% (Y/N)	64	41	58
Current income (USD mean)	219,834[a]	790,372	89,781[b]
Current income per hectare (USD mean)	46[a]	70	573[b]
Current income per visitor (USD mean)	294[a]	140	13[b]

[a] Excludes one outlying MPA with a current income per hectare 200 times larger than the average for the group.
[b] Excludes one outlying MPA with a current income per hectare 150 times larger than the average for the group.

3.1. Relationships within the data

Examination of the income data using the eight variables selected for analysis revealed that MPA size and visitor numbers were significantly related to the total income (respectively, Spearman's rho = 0.45, $p = 0.001$ and rho = 0.75, $p \leq 0.001$). Although there was a significant correlation (Spearman's rho = 0.28, $p = 0.033$) between the GNI per capita of the host country and total MPA income, this relationship is possibly misleading. Location of the MPA appears to be inseparable from the issue of visitor numbers.

As has been shown above, visitor numbers seem to be related to the income an MPA receives. However, visitor numbers are also related to MPA location. MPAs in developed countries tended to have many more visitors (averaging 1562 visitors per hectare per year) than their counterparts in developing countries (averaging 111), possibly because of the greater prevalence of recreation and tourism. Given the significant costs associated with visitors (for MPAs in the survey, on average nearly 20% of the current income is being spent on visitor and education related activities), it seems possible that it is the higher visitor numbers that underpin higher incomes for MPAs based in developed countries rather than the GNI per capita of the host country *per se.*

4. Developing a predictive model for MPA income requirements

A key aim of this study is to analyse the relationships between measured MPA characteristics and income requirements. By understanding the associations between funding needs and these characteristics, the ultimate objective is to be in a position to estimate, for a given MPA, the income needed to meet its management goals. Additional funds for capital investments (such as visitor centres) are not covered by this model, which encompasses only the income required to cover ongoing management costs.

It is important to highlight some of the inherent difficulties in achieving the objective of a predictive model. Firstly, it may not be possible to measure accurately the relationship between a given variable and the income requirements. Secondly, the variables examined here form only a partial picture of the context in which the MPAs operate. There are others that have not been surveyed in this study, such as the condition of, or threats to the resource(s) protected. These might have a significant impact on the funding requirements.

Because of these qualifications, it is not possible to build a comprehensive model of MPA funding needs on the basis of the survey results. The best that can be hoped for is to move towards a better understanding of how MPA income requirements are associated with and determined by a range of factors and characteristics.

4.1. Adjusting the data for the "Funding Gap"

It is first necessary to establish whether the current income levels reflect the true funding needs. If a significant proportion of MPAs is currently failing to meet management objectives as a result of under-funding, any model derived from the current income data will incorporate a bias towards under-funding.

The questionnaire asked MPAs not only to report on the current income levels but also to give an estimate of how much additional funding would be required for them to meet their management objectives. More specifically, respondents were asked to bracket their estimates between the incremental funding that was required at a minimum and the increase that would take them to a funding level regarded as ideal. For the purposes of the forthcoming analysis, the minimum funding requirement (MFR) will refer to the minimum level of income necessary to achieve the aims and objectives of the MPA. Similarly the ideal funding requirement (IFR) will refer to the sum of money needed for an ideal standard of protection and management.

No detailed procedure was laid down for estimating minimum or ideal funding needs. Respondents were asked simply to state a monetary value. This means responses reflected a degree of subjectivity in how respondents interpreted the criterion and in how they estimated additional income requirements. Subjectivity seemed most evident in estimates of the ideal funding requirement. In more than one instance, the estimated ideal funding level was precisely twice the estimated minimum level – possibly a case of "think of a number and double it". This remark is not meant as criticism but highlights the difficulty respondents might have had in answering an open question of this nature.

Forty-nine of 79 replies responded to the questions on minimum income requirements, while 41 out of the 79 specified an ideal income. Responses revealed a broad range of financial viability of the MPAs with some apparently extremely under-funded and others satisfactorily funded, at least to a minimum level. The median percentage increase in income required to meet the minimum funding requirement was 15%, while the increment needed to secure ideal funding was 74%.

Among those MPAs which supplied answers to the relevant questions, five were funded exclusively from visitor fees and each of these regarded their current income levels as acceptable. A further eight were funded by foreign entities, of which five found current incomes acceptable. However, of the 32 MPAs who relied on government funding, only nine were satisfied; eight of the 32 believed their incomes should ideally be more than twice the prevailing levels.

4.2. Selecting the data for analysis

In developing the MPA funding model we used the measure of minimum funding requirement because the figures given, as discussed above, are probably more robust than the IFR and because funding bodies will usually base their decisions on fulfilling the most urgent priorities (the "must-haves", not the "nice-to-haves"). In 15 cases, a figure for the IFR was provided by the respondent but the question on the MFR was left unanswered. In these cases, an MFR for the MPAs was estimated from the IFR in order to increase the sample set for the purposes of modelling. The ratio of MFR to IFR for those MPAs which answered both questions was approximately 0.4 and this was then used to estimate MFR values for MPAs which supplied only IFR data.

Area and visitor numbers were the only variables to show any statistically significant relationship with the minimum funding requirement (area versus MFR: $r = 0.53$, $p < 0.001$; visitor numbers versus MFR: $r = 0.51$, $p < 0.001$).

4.3. Model development

A predictive model of funding needs based on the characteristics of an MPA could be statistical in nature (i.e. based on observed relationships between variables without a detailed attempt to understand the underlying causality) or it could be bottom–up, with an attempt to discover typical execution costs for particular combinations of activities. Ultimately, the most satisfying approach would be the latter, since it would permit a linkage to be drawn between a theory of MPA cost structures and the empirical evidence of how MPAs operate in the real world. Here, we construct a simple bottom–up model – based on a fixed cost/variable cost approach – and test it against the survey findings. As we shall see, although it is not difficult to hypothesise a possible form for a model, testing it against the data presents serious challenges, owing to the very wide range of values that each of the variables in the sample occupies.

In principle, a bottom–up model for income requirements would look at the costs of pursuing various activities. The total running costs of an MPA would then take the form:

$$C_{\mathrm{T}} = C_1 + C_2 + C_3 + \cdots + C_i \cdots$$

where C_{T} = total cost and C_i = cost associated with activity i.

There could be many drivers of C_i, but a basic model might assume that C_i comprised both fixed and variable costs. The fixed costs (or overhead) might reflect, for example, the need for management staff. The variable cost would depend on the value of a particular factor (e.g. area, visitor numbers). This simple hypothetical model might take the following form:

$$C_i = O_i + u_{i1}F_1 + u_{i2}F_2 + \cdots + u_{ij}F_j + \cdots$$

where C_i = cost associated with activity i, O_i = overhead needed for activity i, F_j = value of factor j and u_{ij} = variable unit cost with respect to factor j in pursuing activity i.

Summing across different activities (and assuming, perhaps without justification, that no economies of scale exist across the various overheads) gives this general model:

$$C_{\mathrm{T}} = \sum C_i$$

$$C_{\mathrm{T}} = \sum O_i + F_1 \sum u_{i1} + \cdots + F_j \sum u_{ij} + \cdots$$

where C_{T} = total cost, C_i = cost associated with activity i, O_i = overhead needed for activity i, F_j = value of factor j and u_{ij} = variable unit cost with respect to factor j in pursuing activity i.

In this form, $\sum u_{ij}$ would represent the total variable costs associated with factor F_j summed across all activities that depend on that factor. In effect, this general model forms the basis for a linear multivariate analysis.

As a starting point for exploring relationships in the data, the multivariate model can be simplified to a model that focuses on only one factor. In the case of area, for example, the model would take the following form. Two formulations of the equation are shown. The second is a simple rearrangement of the first, but focuses on the total cost per hectare rather than the total cost *per se*. In principle, both formulations should be linear in their respective variables (area and reciprocal area) if the model holds good.

$$C_{\mathrm{T}} = O + u_a A \quad \text{or} \quad C_{\mathrm{T}}/A = O/A + u_a$$

where C_{T} = total cost, O = overhead, A = area and u_a = variable cost per hectare.

This simplified bivariate model provides the basis for a preliminary exploration, using linear regression techniques, of how a particular variable influences income requirements.

Before attempting to analyse the data statistically using this basic model, it is worth demonstrating that some form of positive correlation does exist between the minimum income requirement (i.e. MFR) and MPA area. Fig. 2 shows the MFR for each MPA plotted against how that MPA ranks by area within the sample. The tendency for those MPAs with larger areas to have higher income requirements – clearly visible as a general pattern in Fig. 2 – suggests that area might indeed be an important determinant of the income requirements. This rank-based approach is particularly useful in circumstances where the raw data cover several orders of magnitudes (from 10^1 up to 10^6 for area and from 10^4 up to 10^7 for income). As we shall see shortly, tests based on a least-squares method can give rise to misleadingly high correlations in such circumstances.

In Fig. 3, we revert to the basic bivariate model from the previous section and investigate the relationship between income requirements and area using standard regression techniques. The study in Fig. 3 uses the second formulation of the basic model, focusing on the minimum funding requirement per hectare as a function of the reciprocal of MPA area. In principle, either formulation could have been used for the regression analysis. By focusing on the income requirement per unit area, the intention was to bring the data points within a more manageable range. This objective proved elusive.

The regression analysis in Fig. 3, based on a sample of 50 MPAs, implies that each protected area requires a mean annual overhead of approximately USD 96,000 plus an additional annual area-based income of USD 28 per hectare.

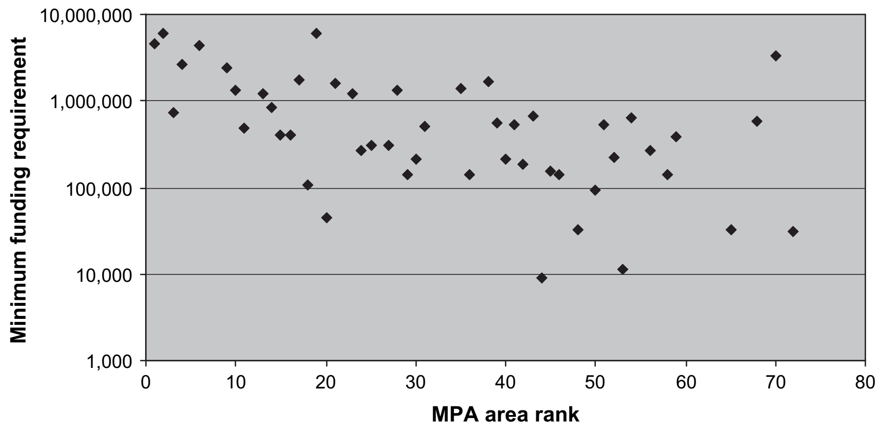

Fig. 2. Minimum funding requirement (in USD) against MPA area rank.

On the face of it, the results of the regression appear encouraging, with $R^2 = 0.95$ for the area model (and 0.80 for visitor numbers). However, a closer examination of the data reveals a flaw in this approach, which means the apparent strength of the regression must be treated with scepticism. The distribution of the data inputs, which one had hoped might be better accommodated by focusing on the MFR per unit area, remains a fundamental problem. Since the data for area and visitor numbers cover many orders of magnitude, the density of data points across the sample is not uniform when analysed on a linear scale. In practice, the density of data points increases rapidly approaching the origin. This clustering will tend to generate falsely high correlations in regression tests because the greatest weight will be given to the few outermost points while all of the points clustered near the origin will appear to be in close proximity – as far as the regression mathematics is concerned – to the line of best fit.

What began as an attempt to build a bottom–up model for MPA funding requirements must be abandoned, for now, in the absence of sample data that are reasonably evenly distributed in linear space. With data that are fairly evenly distributed in log space, the obvious conclusion to draw is that any regression-based approach will yield meaningful results only if applied to log data. This is the approach adopted in the next section.

Moving from a model based on absolute data to a model based on log data is not without analytical cost. In practice, it will be difficult to relate regressions based on log data easily to any bottom–up model because the intervening mathematics is more complex. In effect, any relationship found in the log data will have to be seen as largely statistical in nature (rather than as grounded in a detailed understanding of the cost of pursuing various activities). Here we develop a multivariate model relating log MFR with log MPA area and log visitor numbers.

Multivariate model:

$$\log \mathrm{MFR} = a \log A + b \log V + c$$

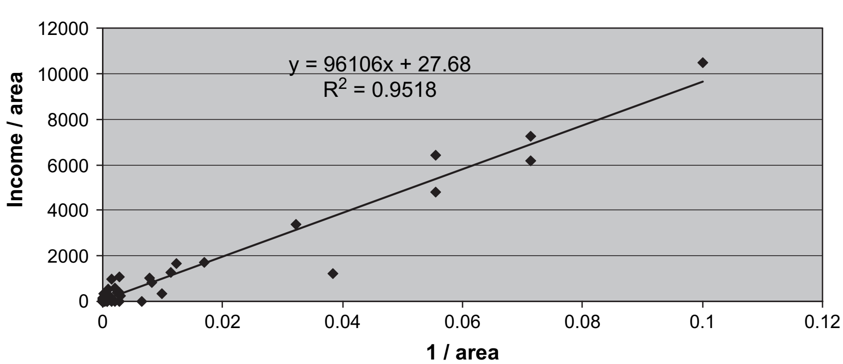

Fig. 3. Income per unit area (USD per hectare) versus the reciprocal of area.

where MFR = minimum funding requirement, A = area, V = visitor numbers, a, b = regression coefficients and c = regression constant.

Multiple regression results on data from 51 MPAs produced the results summarised in Table 2. The adjusted R^2 from this analysis was close to 0.46, with the standardised coefficients suggesting that area made a slightly greater contribution to the result than the visitor numbers.

Fig. 4 illustrates the quality of fit of the model results plotted against observed values. The R^2 of 0.46 is apparent from this chart, with a broad distribution of the observed values around the modelled line. The standard deviation of the residuals (the difference between observed and predicted values) around the line of best fit is approximately 0.45, illustrated by the two channel lines, separated on either side of the modelled line by one standard deviation. It is clear that the two-variable model provides a useful but incomplete description of the MPA funding requirements. Furthermore, there seem to be no obvious patterns in the residuals, a subject to be discussed in more detail shortly.

In order to demonstrate the predictive range of the model, the equation of best fit is presented below, with an estimated error of ±one standard deviation.

$$\log \mathrm{MFR} = 0.202 \log A + 0.206 \log V + 3.959 \pm 0.45.$$

It should be noted that the additive error of ±0.45 in the predicted log data corresponds to a multiplicative error of $10^{\pm 0.45}$ in the predicted underlying data (i.e. approximately 2.8 times). In practice, this means that if a hypothetical MPA had a predicted value for minimum income of USD 1.0 million (based on area and visitor numbers), the actual figure could range from USD 350,000 up to USD 2.8 million within one standard deviation of the log model. Such a broad range is not entirely unexpected. The complexity of circumstances in which MPAs operate make it unlikely that a simple model can explain with precision the income requirements that would apply in a particular context.

Statistical tests suggested that there was no significant relationship between any of the other variables assessed in this survey and MPA funding needs. Habitat, purpose, zonation, the benefit to fisheries and the geographical location of the MPA appeared to have no bearing on the minimum amount of income sampled MPAs required to fulfil their objectives. However, it is probable that some or all of these other factors do have some impact on the income requirements which, although insignificant in their own right, when combined would explain a reasonable but indeterminate amount of the residual. A larger sample of MPAs would allow a more powerful analysis of their relationships with the MFR. In addition, it is likely that the questionnaire failed to reveal sufficient detail as to the nature of variables measured. Taking the example of zonation, the survey did not solicit a detailed breakdown of the zonation patterns on the basis of size and activity. It is likely that the minimum funding requirement will be dependent on the nature and scale of zonation-related activities. There are also a number of other factors which might be expected to influence the ongoing funding requirements of an MPA, but were not tested in this survey. An example of one such factor is an MPA's maturity. An MPA in the initial stages of development and implementation, for example, is likely to have differing income needs to an established MPA which may be undertaking a re-evaluation or plan revision.

Having established the overall relationship between area and visitor numbers and the minimum funding requirement, we explored differences in the model across the three main clusters identified within the sample. It was anticipated that applying the model to the requirements of the different ''types'' of MPAs would have the potential to explain some of the residual differences between the observed MFR and the predictive model. For example, if Cluster A had showed very different requirements to clusters B and C, it might have been surmised that the benefit to fisheries

Table 2
Results of multiple regression model

R	R^2	Adjusted R^2	Standard error of the estimate
0.693	0.48	0.458	0.4611

	Unstandardised coefficients		Standardised coefficients		
	B	Standard error	Beta	T	Significance
Constant	3.959	0.254		15.608	<0.001
Area	0.202	0.043	0.491	4.663	<0.001
Visitor numbers	0.206	0.052	0.418	3.965	<0.001

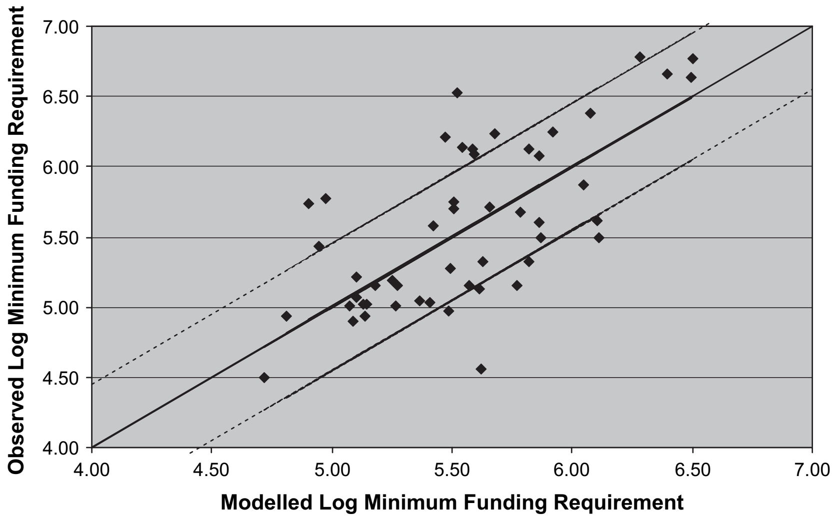

Fig. 4. Observed minimum funding requirement (MFR) compared with predicted MFR (channels show ± one standard deviation).

was a determinant of the MFR. In reality, no such difference was apparent – interestingly, the clusters showed no obvious patterns in their requirements despite the differences in visitor numbers and area between the clusters.

5. Summary and conclusions: appreciating complexity and context

The aim of the study was to investigate the income requirements of marine protected areas and their dependence on the quantitative and qualitative factors that characterise specific MPAs. The underlying goal was to explore whether it is possible to construct a predictive tool that could be used for planning purposes to estimate income requirements for future MPAs based on characteristics that could be readily measured or estimated.

In order to collect empirical information from existing MPAs, questionnaires were sent to approximately 500 MPAs worldwide in which the recipients were asked to supply data that described the circumstances and objectives of the MPA, as well as to give their estimates for current income, the income that would allow them minimally to meet their objectives and the ideal level of funding. Responses were received from 79 MPAs with a broad distribution across geographies and purpose. Quantitative data for the major items (e.g. size, visitor numbers and income) typically covered many orders of magnitude, from the very small to the very large.

A cluster analysis based on eight variables indicated that the sample MPAs could be grouped into three broad categories: (a) those with relatively low visitor numbers, often located in developing countries and focused on fisheries and enforcement; (b) those with a broad range of purposes from recreational to commercial; and (c) an irregular group with relatively low visitor numbers, restrictive objectives and a possible conservation bias.

A broad range of statistical techniques – predominantly based on bivariate analysis – was used to analyse relationships in the data with a view to understanding which variables might be related to income requirements. Income dependency was tested against factors such as MPA size, purpose, type of habitat, visitor numbers, parent nation wealth, source of funds and zonation.

Of the variables assessed, area and visitor numbers were found to be the most important drivers of minimum income requirements – and the only factors for which a quantitative trend could be established. For area, the correlation metrics were $r = 0.53$, $p < 0.001$. For visitor numbers, the metrics were $r = 0.51$, $p \leq 0.001$. Based on these findings, two approaches were undertaken to build more detailed multivariate models.

In the first of these, a bottom–up model was put forward for testing, based on the hypothesis that MPAs typically undertake a variety of tasks and that the income required for these might be related to the two identified variables through a simple (i.e. linear) fixed cost/variable cost model. This approach gave superficially interesting results ($R^2 = 0.95$ for area, 0.80 for visitor numbers) but the authors determined that these results were deceptively high and mostly a consequence of the very wide range of values for the key data, which covered many orders of magnitude.

In the second approach, a multivariate model was constructed based on a linear combination of log data. The logarithmic approach gave rise to a data set that was more evenly distributed across the sample and therefore more susceptible to regression-based analyses. At the same time, by parting company with a bottom–up model, the opportunity for a detailed explanation of the underlying mechanisms was passed over in favour of a more statistical top–down approach. The log model (with the structure log (income) $= a$ log (area) $+ b$ log (visitor numbers) $+ c$) gave rise to a measured correlation of $R^2 = 0.46$. There were no discernable patterns across the three classification categories identified in the cluster analysis.

The significance of area to income requirements was of little surprise given its profile in the literature (e.g. Refs. [22,26]). However, the relationship between visitor numbers and funding needs was interesting and might go some way to explaining why apparently well financed northern hemisphere MPAs still claim to be under-funded. It could be that their income is directed away from core conservation-related activities to activities such as providing information, toilets and car parks. The fact that for the MPAs in the survey, on average nearly 20% of the current income is being spent on visitor and education related activities tends to support this assumption. The understanding of the relationship between income and visitor requirements may have important implications not only for the level of income an MPA requires, but also from where it is obtained. Given that this substantial proportion of the income an MPA requires is being utilized for amenity purposes, a case may be made for funds to be provided from the typically more robust government social and educational as well as environmental budgets.

Another important conclusion which may be drawn from the study is that the specific context in which each MPA operates – embracing physical characteristics such as area and location, demands on resources such as visitors and enforcement, elective activities such as community relations and education and, finally, the ultimate aims and objectives of the MPA such as the preservation of economically valuable resources or environmentally motivated conservation – results in considerable complexity. This complexity makes the goal of a unified predictive model of income requirements elusive. What is clear from the study, however, is that the effective management of MPAs is costly – with the presence of visitors increasing the burden. With visitor numbers for many successful MPAs likely to grow over time, it would seem prudent to cope with increasing demands by building a visitor fee structure into any sustainable financing programme. For this strategy to be effective, visitor fees need to be set at a sufficiently high level. This would imply that a significant increase from the current fee levels is required. The survey shows that even with the present levels of under-funding, MPAs receive USD 19 per visitor compared to the USD 2–3 levied per diver by many Caribbean MPAs [27]. Both real life examples such as Bunaken National Park in Indonesia which charges USD 15 [28] per visitor and WTP (willingness to pay) studies done on some Caribbean sites, which indicate a WTP of USD 20 per person [29,30], suggest that there is a great deal of room for MPAs to increase their user fees.

One important limitation of this analysis is that it only considered running costs. Potentially the most significant of all of the costs associated with an MPA are the opportunity costs. The day-to-day expenses of running an office and visitor centre might be dwarfed by the economic returns foregone in order to establish an MPA and ensure its objectives are met. These returns might include development profits foregone to avoid pollution and siltation of the site or fishing revenues forsaken by displaced communities (although MPAs that protect sites from fishing may increase catches beyond their boundaries [7]). All too often in the MPA literature, the broader context of the MPA itself – beyond that of the local community – is ignored or only referred to in passing. The full implications of changing the development plans for a wide area must be considered in any MPA-based conservation strategy.

As a final point, a focus on costs does not provide the full picture. Only gross costs were analysed in this survey. As important, if not more important than understanding the cost structure of MPAs, is understanding their economic benefits, both existing and potential. As many studies have already indicated, the apparent costs of running an effective MPA might in many cases be more than offset by their attendant economic benefits. In Balmford et al.'s 2003 study [26], the estimated annual USD 5–19 billion cost of running a global system of MPAs is dwarfed by the contribution it would make to maintain the healthy functioning of marine ecosystem services valued at many trillions of dollars [31].

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