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Balmford, A., Gravestock, P., Hockley, N. et al. (2 more authors) (2004) The worldwide costs of marine protected areas. Proceedings of the National Academy of Sciences of the United States of America. pp. 9694-9697. ISSN: 1091-6490

https://doi.org/10.1073/pnas.0403239101

The worldwide costs of marine protected areas

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Communicated by Norman Myers, University of Oxford, Oxford, United Kingdom, May 11, 2004 (received for review December 23, 2003)

Declines in marine harvests, wildlife, and habitats have prompted calls at both the 2002 World Summit on Sustainable Development and the 2003 World Parks Congress for the establishment of a global system of marine protected areas (MPAs). MPAs that restrict fishing and other human activities conserve habitats and populations and, by exporting biomass, may sustain or increase yields of nearby fisheries. Here we provide an estimate of the costs of a global MPA network, based on a survey of the running costs of 83 MPAs worldwide. Annual running costs per unit area spanned six orders of magnitude, and were higher in MPAs that were smaller, closer to coasts, and in high-cost, developed countries. Models extrapolating these findings suggest that a global MPA network meeting the World Parks Congress target of conserving 20–30% of the world's seas might cost between $5 billion and $19 billion annually to run and would probably create around one million jobs. Although substantial, gross network costs are less than current government expenditures on harmful subsidies to industrial fisheries. They also ignore potential private gains from improved fisheries and tourism and are dwarfed by likely social gains from increasing the sustainability of fisheries and securing vital ecosystem services.

The world's oceans are in trouble. Global fish catches are declining (1), numerous populations of marine animals have collapsed (2–5), and communities and habitats have been extensively damaged or destroyed (6–10). Evidence is mounting that marine protected areas (MPAs), where fishing and other human activities are restricted or prohibited, conserve habitats and populations (1, 11–13) and, by exporting biomass, may also sustain or increase the overall yield of nearby fisheries (1, 11, 12). There has been considerable progress in identifying priority areas and efficient MPA configurations for marine conservation (14, 15). However, despite their growing significance for policy, we have virtually no data on how much MPAs cost to establish and run, how these costs vary, or whether a substantially expanded global network of MPAs could be afforded. To address these questions, we conducted the most extensive survey to date of how much MPAs cost.

Our Survey

To evaluate the costs of MPAs, we sent a questionnaire (see supporting information, which is published on the PNAS web site) to ≈500 individuals involved in running MPAs worldwide. We requested information on MPA area, protection type and goals, staffing, recurrent income and expenditure, and how much (if any) extra expenditure and staff were required for minimum effective protection. We supplemented questionnaire returns with information from the published and gray literature. All costs were converted to year 2000 U.S. dollars by using the local currency to U.S. dollar exchange rate for the reported year and a U.S. gross domestic product deflator index.

We excluded from our analyses MPAs whose marine components covered <50% of the MPA area. In order for our calculations to overestimate, if anything, the costs of marine conservation, for all other partially terrestrial reserves, we attributed all costs to their marine sector if we did not have a more detailed cost breakdown. To be similarly conservative, we excluded five MPAs whose questionnaire returns suggested that, despite having no budget at present, they required no extra money.

This left us with data for a total of 83 MPAs worldwide (12 from Africa, 12 from Asia, 10 from Australasia and Oceania, 13 from Europe, 13 from Latin America and the Caribbean, and 23 from North America), ranging in size from <0.1 km^2 to >300,000 km^2. As well as encompassing a broad geographic and size range, our sample included a wide spectrum of management types (run by government agencies, nongovernmental organizations, and local communities; zoned and not zoned), objectives (e.g., biodiversity protection, recreation, conflict reduction, and fishery enhancement), and resources protected (e.g., coral reefs, whales, and coastal scenery). Of the 76 MPAs that reported their purpose, 75 (98.7%) listed habitat and species protection (the remaining MPA was solely for research), and protection was the primary purpose for 58 (76.5%). Therefore, our sample is broadly representative of the range of MPAs in use worldwide (16), and should produce a meaningful approximation of the costs of running a global MPA system, with one important caveat: because questionnaires were only distributed to MPAs for which we could obtain contact details, and only 16% responded, our figures are probably biased toward relatively well managed and funded MPAs.

Budgets of MPAs

Recurrent annual expenditure on the MPAs sampled, expressed per km^2, ranged from zero to >$28 million per km^2 per year (median, $775 per km^2 per year; all costs are given in year 2000 U.S. dollars). Despite our likely bias toward better-funded MPAs, only 13 of the 83 sampled (15.7%) reported that current funding was sufficient for effective conservation. On average, current income met around one-half of the estimated total amount required annually (median across 75 MPAs, 44.8%), in developed and developing country MPAs alike (see below). Taking this underspend into account, the total costs per unit area of running the marine protected areas in our sample varied enormously, with the sum of current expenditure plus estimated shortfall ranging from ≈$4 per km^2 per year to nearly $30 million per km^2 per year (median, $2,698 per km^2 per year), and with the proportion of the total expenditure required that is currently met tending to be lower in reserves with higher total costs per unit area (Spearman rank correlation: $r_s = -0.24$, $n = 83$ MPAs, $P < 0.05$). This dramatic variation in running costs mirrors that recently reported for terrestrial conservation programs (17).

Predicting Variation in Costs

To explore this variation in MPA running costs, we collected information on a suite of potential predictors of cost: the approximate number of people living within 50 km of the MPA, extracted by using ARC-INFO software from a global surface modeled at 5′ resolution (18); the distance of the centroid of the MPA from the nearest inhabited land; and per capita gross

Abbreviations: MPA, marine protected area; GNP, gross national product; PPP, purchasing power parity.

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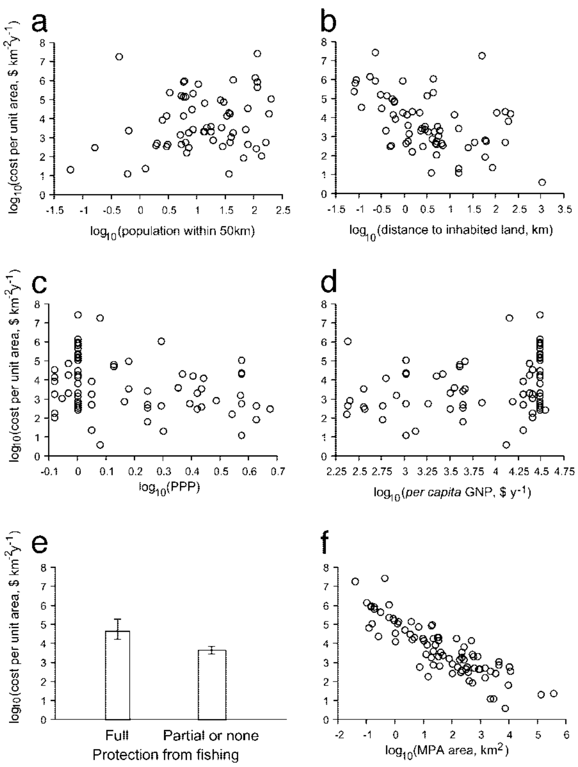

Fig. 1. The total annual cost per unit area of running MPAs in relation to the number of people living within 50 km (*a*); distance from inhabited land (*b*); national PPP (*c*); per capita GNP (*d*); whether or not the MPA was wholly protected from fishing (*e*); and MPA size (*f*). The columns in *e* give means ± SE of $\log_{10}$-transformed costs.

national product (GNP) and purchasing power parity (PPP, a measure of the local purchasing power of one U.S. dollar) in the country under whose jurisdiction the MPA lies (for 1999, from ref. 19 and supplemented for nonreporting countries by estimates kindly provided by World Bank staff). These data were not available for all 83 MPAs.

Looking first simply at how current expenditure in MPAs and shortfall per unit area compare between developed and developing countries, we found that the percentage of estimated total (current plus shortfall) requirement currently met did not differ between MPAs in the two groups of countries (Wilcoxon–Mann–Whitney test comparing 39 developed country and 36 developing country MPAs: $z = 1.81$, not significant). However, estimated total running costs per unit area were greater for MPAs in developed countries (43 developed country vs. 40 developing country MPAs: $z = 2.24$, $P < 0.05$; median costs, \$8,976 vs. \$1,584 per km^2 per year, respectively).

Further analysis revealed that the total annual cost per unit area of running an MPA was independent of the number of people living within 50 km ($r_s = 0.19$, $n = 68$ MPAs, not

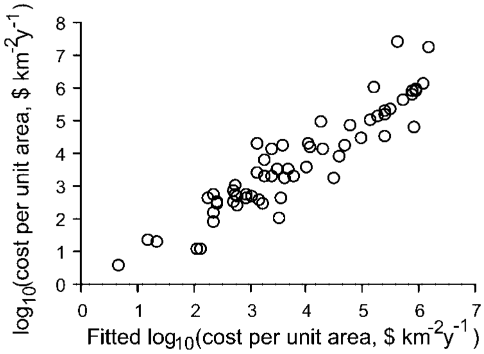

Fig. 2. The total annual cost per unit area of running MPAs plotted against fitted cost, estimated from the three-term model described in Table 1.

significant; Fig. 1*a*), but decreased the more distant an MPA was from inhabited land ($r_s = -0.52$, $n = 68$, $P < 0.001$; Fig. 1*b*). Costs also decreased weakly with PPP ($r_s = -0.30$, $n = 74$, $P = 0.01$; Fig. 1*c*), increased weakly with per capita GNP ($r_s = 0.33$, $n = 74$, $P < 0.01$; Fig. 1*d*), and were higher for MPAs that were fully protected from fishing (Wilcoxon–Mann–Whitney test comparing 13 fully protected vs. 58 less protected MPAs: $z = 2.57$, $P = 0.01$; Fig. 1*e*). However, the strongest correlation was with MPA size: per unit area, bigger MPAs cost substantially less to run ($r_s = -0.86$, $n = 83$, $P < 0.001$; Fig. 1*f*).

We next built models for predicting overall variation in MPA costs by using the same independent variables but where necessary $\log_{10}$-transforming them to achieve approximate normality. Here we report the results of weighted regressions where, to adjust the influence of data points in relation to each country's significance for marine conservation and its representation in our sample, we weighted each point by the ratio of its country's area of continental shelf (from ref. 20, coastline data are available at http://geocompendium.grid.unep.ch/data_sets/coastal/nat_coastal_ds.htm) to the number of MPAs sampled from that country; hence, data points from poorly sampled countries or countries with large continental shelf areas received greater weight than others. Note, however, that all our results were qualitatively unchanged when nonweighted regressions were used.

We found that just three variables could predict nearly all of the variation in total MPA running costs (Fig. 2 and Table 1). By far the best single predictor of total annual running cost per unit area was MPA size; by itself $\log_{10}$ (MPA area) predicted almost 80% of the variance in $\log_{10}$ (cost per unit area) (Table 1), with the slope of the relationship (-0.80 ± 0.05 SE) being strikingly similar to estimates recently derived for global (-0.85; ref. 17) and South African (-0.70; ref. 21) terrestrial reserves. This model could be significantly improved by adding in distance from inhabited land and PPP, with running costs decreasing with both increasing isolation and increasing PPP, independently of MPA size (Table 1). This final three-term model was identified as the best by both forwards and backwards stepwise procedures

Table 1. Regression models predicting variation in the total running costs per unit area of running MPAs, and the number of jobs per unit area provided by MPAs

			Independent variables (coefficient, *t*, *P*)			
Dependent variable	No. of MPAs	Intercept	$\log_{10}$ (MPA area, km^2)	Distance from inhabited land (km)	PPP	Overall r^2, *P*
$\log_{10}$ (cost per unit area, dollar km^{-2} y^{-1})	80	5.02	−0.80, −17.2, <0.001			0.79, <0.001
$\log_{10}$ (cost per unit area, dollar km^{-2} y^{-1})	61	5.62	−0.72, −18.0, <0.001	−0.002, −5.26, <0.001	−0.30, −6.99, <0.001	0.90, <0.001
$\log_{10}$ (full-time jobs per unit area, km^{-2})	54	0.85	−0.77, −8.94, <0.001			0.61, <0.001

(neither per capita GNP nor whether there was full protection from fishing could improve the model); it accounted for >90% of the variance in $\log_{10}$ (total annual cost per unit area).

These results show that MPAs cost more to run, per unit area, where they are small, where they are close to inhabited land, and where cost structures are high. We can use such models to estimate the running costs of individual MPAs with reasonable accuracy, but we can also combine them with models of the extent and configuration of idealized MPA networks to estimate the costs of a global system of MPAs.

Costing a Global MPA Network

The World Summit on Sustainable Development (WSSD) commitment to establishing national MPA networks by 2012 set no targets for number, size, or coverage of MPAs, but the World Parks Congress (WPC) recommendation explicitly calls for strictly protected marine reserves covering 20–30% of habitats by 2012 (see sections 5.22 and 5.23 of www.iucn.org/themes/wcpa/wpc2003/pdfs/outputs/wpc/recommendations.pdf). Such an ambitious target is supported by recent estimates of the overall fraction of the ocean that needs to be protected from fishing to sustain fisheries outside MPAs. These range from 10% to >50% (depending on the objectives considered), around a modal value of ≈30% (12). We therefore used our findings to explore the costs of global marine conservation systems ranging in total coverage from 1% to 40% of the marine surface.

We identified possible configurations of networks meeting coverage targets of 1–40% through a set of models that explicitly allowed MPAs to merge (to varying degrees) with increasing coverage. The models were run on a 9,438 km × 9,438 km grid (representing ≈25% of the total marine area), at 1-km^2 resolution. Each of four versions was run 100 times, and began with the designation of randomly located MPAs whose sizes were drawn at random from the approximately log-normal size–frequency distribution recorded by Kelleher and coworkers in their global survey of 991 MPAs (table 2 of ref. 16). Because the 991 MPAs in this global data set together cover ≈0.29% of total marine area, in our models we continued this first step until 0.29% of the grid's area was covered in MPAs. After that, each version continued to select new MPAs from the size distribution in ref. 16 until 40% of the grid was reserved, with (*i*) new MPAs being randomly located, with no coalescence of neighboring MPAs allowed; (*ii*) new MPAs being randomly located, but with all neighboring MPAs allowed to coalesce (so that some became larger than those in the data set in ref. 16); (*iii*) currently unreserved cells adjacent to already reserved cells being 10% more likely than other cells to be picked for reservation, and with coalescence allowed; or (*iv*) currently unreserved cells adjacent to already reserved cells being 50% more likely than other cells to be picked for reservation, and with coalescence allowed.

Total annual running costs for each MPA were estimated simply from the MPA's size (using the first regression model in Table 1). These were then summed for all MPAs in a given run, and overall costs averaged across all 100 runs of each model.

The results show that, although overall running costs of an MPA network increase with coverage, economies of scale mean that MPA mergers can achieve considerable cost savings (Fig. 3). In the absence of such coalescence (model a), costs rise in direct proportion to coverage, with running costs for a global MPA system estimated at \$12.5 billion per year for 20% coverage and \$18.8 billion per year for 30% coverage. With random coalescence (model b), the marginal cost of additional MPAs decreases with increasing coverage, and running costs for 20% (30%) coverage fall to \$10.4 (\$13.9) billion per year. With increasingly directed coalescence, estimated costs for 20% (30%) coverage decrease further to \$9.5 (\$12.4) billion per year under model c, and \$5.4 (\$6.9) billion per year under model d. Costs for less

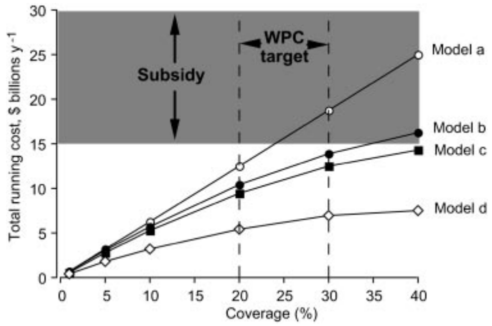

Fig. 3. Total estimated running costs of MPA systems covering 1–40% of the world's seas, according to four different models of system expansion. The shaded area denotes recent estimates of global subsidies to industrial fisheries (see text), whereas the vertical dashed lines show the MPA coverage recently recommended by the World Parks Congress. Model a, new MPAs randomly located, with no coalescence allowed; model b, new MPAs randomly located, but with all neighboring MPAs allowed to coalesce; model c, currently unprotected cells adjacent to already protected cells being 10% more likely than others to be picked for reservation, and with coalescence allowed; model d, as for model c, but with 50% greater likelihood of adjacent cells being picked.

extensive systems of MPAs would be correspondingly lower (Fig. 3).

Coalescence of MPAs is likely (and model a is unlikely) because, besides their lower costs, fewer, larger MPAs will probably be politically and administratively easier to establish and run than would more, smaller MPAs of the same total area. They will also generally be more desirable biologically because many marine species as well as crucial ecological processes have very large spatial requirements (4, 11, 15). Nevertheless, small reserves may be appropriate where marine habitats are patchily distributed, and coalescence may be further constrained insofar as extremely large no-take MPAs may reduce overall fish catches.

An identical approach to that used to estimate recurrent costs of a global MPA network can be used to estimate how many fulltime protected area management jobs it would create. Across our sample of MPAs, $\log_{10}$ [MPA area] predicts 61% of the variance in $\log_{10}$ [total number of jobs required per km^2] (n = 54; $P < 0.001$; Table 1). Applying this to the portfolio of MPA areas generated by model b suggests that a global MPA network would directly provide ≈830,000 (20% coverage) to 1.1 million (30% coverage) fulltime jobs in MPA protection; to the extent that effective protection boosted net fish catches, it could also increase fisheries-related employment.

Limitations and Caveats

Our estimates of overall network costs are approximate and have limitations. For example, they do not attempt to partition spending between strictly protected marine reserves and other MPAs. Likewise, we do not address where MPAs will be established: because we have no information on the desired global distribution of reserves across countries or with distance from the shore, our models do not incorporate the statistically significant relationships we uncovered between MPA running costs and isolation or PPP. In practice, MPAs are generally smaller closer to the shore (e.g., in our sample, Spearman rank correlation of MPA size vs. distance from inhabited land: r_s = 0.61, n = 73 MPAs, $P < 0.001$), so expenditure will be disproportionately concentrated in inshore areas, whereas high seas conservation will be far cheaper.

Our numbers also do not include several potentially important costs. First, lack of data means we were unable to address start-up costs or the costs of building local and national capacity and political support for MPAs. Second, we exclude any costs of improving watershed management on land to reduce impacts offshore (note however that these are covered in equivalent terrestrial estimates; ref. 22). Third, we do not take account of any opportunity costs of MPAs in terms of a net decrease in fishing offtake, because opinions on this issue are clearly divided: several theoretical studies (refs. 23–26; but see ref. 27) suggest that MPAs will increase net harvests only under a narrow range of conditions (so opportunity costs may be commonplace), whereas some field studies (reviewed in ref. 12) provide empirical evidence of net gains to fishing (which may in turn help offset management costs).

On the other hand, there are a number of reasons why we may have overestimated the costs of MPA conservation. Our models assume that the size distribution of existing MPAs provides a sensible starting point for estimating the sizes of future components of an expanded MPA network; in practice, MPA coalescence may become much more marked than envisaged here, leading to substantial savings through resulting economies of scale. Likewise, we have assumed that no savings are achieved over time through the identification and dissemination of best management practice. Last, our models assume zero income to MPAs from tourism; in reality, income from visitor and other user fees already funds a significant proportion of MPA management activities (unpublished data) and could fund more, particularly in coral reef areas (28).

Global MPA Costs in Context

Despite these uncertainties, we can conclude that marine conservation on the scale examined here would undoubtedly be expensive. A global MPA network covering 20–30% of the seas and costing $5–19 billion per year to run would require we increase our present areal and financial investment in marine conservation by around two orders of magnitude.

However, the return on such an investment would be substantial. Aside from any direct financial gains from potentially increased catches, the MPA system modeled here would increase the sustainability of a global marine fish catch currently worth $70–80 billion annually (29). It would also help ensure the continued delivery of largely unseen marine ecosystem services with a gross value, according to one estimate, of roughly $4.5–6.7 trillion each year (i.e., 20–30% of the $22.3 trillion per year, in 2000 U.S. dollars, total for nonextractive marine services in ref. 30).

Most significantly, an ambitious program of MPA expansion could probably be instituted for less than the amount already spent by developed world governments on harmful subsidies to industrial fisheries. These subsidies currently run at between $15 and $30 billion each year (in year 2000 U.S. dollars; refs. 31–34; Fig. 3). As well as subsidizing overfishing in domestic and international waters, these payments subsidize developed world boats to overfish developing-world stocks (1, 31, 33- 38). Although it may be argued that fishing subsidies safeguard jobs, such protection is only transient, as illustrated by the loss of tens of thousands of jobs after the collapse of the heavily subsidized Grand Banks cod fishery (39). Moreover, a global network with 20–30% coverage (expanded according to model b) could itself directly provide around one million fulltime jobs in MPA protection, almost certainly more than are maintained by all fishing subsidies worldwide (29).

We are very grateful to many colleagues around the world, too numerous to mention individually, for providing cost data; Kat Munro and Kate Trumper for helping collate this information; John Dixon and Katie Bolt at the World Bank for providing supplementary economic information; Simon Blyth for geographic information systems work; Rashid Sumaila for advice on subsidies; Rhys Green and Jörn Scharlemann for statistical help; Neil Burgess, Ghislaine Llewellyn, and Matt Rayment for help in designing and distributing questionnaires; Adam Tomasek for logistical support; the Royal Society for the Protection of Birds and World Wildlife Fund for financial help; and Neil Burgess, Rhys Green and three anonymous referees for valuable comments on an earlier draft of the manuscript.

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