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Valuing the ecosystem services of the Chagos: a review of challenges and estimates

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ABSTRACT: This study provides a preliminary review of the economic value of the ecosystem goods and services of the Chagos Islands, central Indian Ocean, in the period immediately prior to the designation of the Chagos marine reserve in April 2010. The goods and services valued include inshore and offshore fisheries, shoreline protection, scientific value, the islands' possible role in supporting southwest Indian Ocean fisheries and in southwest Indian Ocean reef recovery and its value as a unique and unspoiled ecosystem. The goods and services identified were largely intangible, with few associated directly with a market. Both the nature of the subject, particularly the significance of its non-use values and the uniqueness of the site, as well as incomplete data, presented valuation challenges. In order to accommodate these characteristics, estimates of annual economic flow were provided in addition to economic values. The study estimated possible annual economic flows of several hundred million pounds, with an economic value in excess of £1 billion (£10^9), with the benefits accruing both regionally in the southwest Indian Ocean and globally.

KEY WORDS: Chagos Islands · Economic value · Southwest Indian Ocean · Ecosystem goods and services

INTRODUCTION

This study reviews the economic value of the ecosystem goods and services of the Chagos Islands, central Indian Ocean. Ecosystem goods and services are the benefits that human populations derive from ecosystem functions (Costanza et al. 1997). There are many incentives to advance the understanding of the economic value of ocean and coastal ecosystems. Foremost amongst them is to improve the management, governance, regulation and policy relating to marine resources — especially in a rapidly changing ocean environment (TEEB 2012). The rationale for valuing the ecosystem goods and services of the Chagos is particularly strong. Not only are these goods and services abundant and highly significant, but their benefits might be felt far beyond their own waters, in the rest of the southwest Indian Ocean (SWIO) and beyond. This review examines the value of ecosystem goods and services in the Chagos in the years immediately preceding the creation of the Chagos marine reserve on 1 April 2010. Both the nature of the subject and the absence of data inhibit the production of a single sum for the Chagos as a whole, so instead the approach has been to consider measures of economic flows as well as estimated economic values. The Chagos provides important insights into valuation in an area where much data is not available.

Background

The Chagos

The Chagos is the geographical name of the British Indian Ocean Territory (BIOT). It is comprised of 55 islands and the world's largest remaining coral atoll, the Grand Chagos Bank (Sheppard et al. 1999). The

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archipelago is in the central Indian Ocean, lying at the southernmost end of the Lakshadweep–Maldives–Chagos ridge (Sheppard et al. 1999). The islands, which have been governed by Britain since 1814, were evacuated between 1965 and 1973 on the creation of the BIOT and US military base (Evers & Kooy 2011). Four atolls are now uninhabited and apart from some poaching, the 60 000 km^2 of reefs are not impacted by direct human activities (Harris & Sheppard 2008). In April 2010, the UK Government announced the creation of a no-take marine protected area (MPA) in the territory which, extending to 640 000 km^2, is the largest no-take area in the world (Koldewey et al. 2010).

Valuing the ecosystem services of the Chagos

Placing an economic value on ecosystems expresses people's preferences for the goods and services they provide in monetary terms. Fig. 1 shows commonly used groupings as they apply to the goods and services of the Chagos: the 3 categories — use, non-use and option — sum to the total economic value (TEV) of the ecosystem (Goulder & Kennedy 1997).

It needs to be kept in mind that each ecosystem will have attributes which determine (1) how a valuation should be undertaken; (2) what types of primary and/or secondary data should be sourced; (3) what economic tools and instruments should be used; (4) the nature of the findings; and (5) the extent to which the outputs represent a comprehensive valuation. In the case of the Chagos, our understanding of the ecosystem goods and services has 3 key characteristics which will impact significantly upon the study:

- Incomplete knowledge. There is incomplete understanding of the ecosystem functions of the Chagos and their relationship with the goods and services they provide, as is the case for many ecosystems (Perrings & Pearce 1994). Here, the biological links between the islands and reefs with the rest of the SWIO are only now being recognised (Sheppard et al. 2012, 2013)
- Relevance of non-use values. A key characteristic of the Chagos that will shape the valuation is the likely importance of non-use values as a proportion of the whole. Non-use benefits are notoriously hard to value, with unresolved questions relating to the validity of the monetary estimates (Pascual & Muradian 2010) with very few published analyses incorporating these elements (Sumaila 2008a)
- Uniqueness. The features of the Chagos that make it so attractive for conservation purposes are also those that make it very rare in biological terms. Its size and condition is unique in the Indian Ocean and it is one of only a tiny handful of similar sites in the

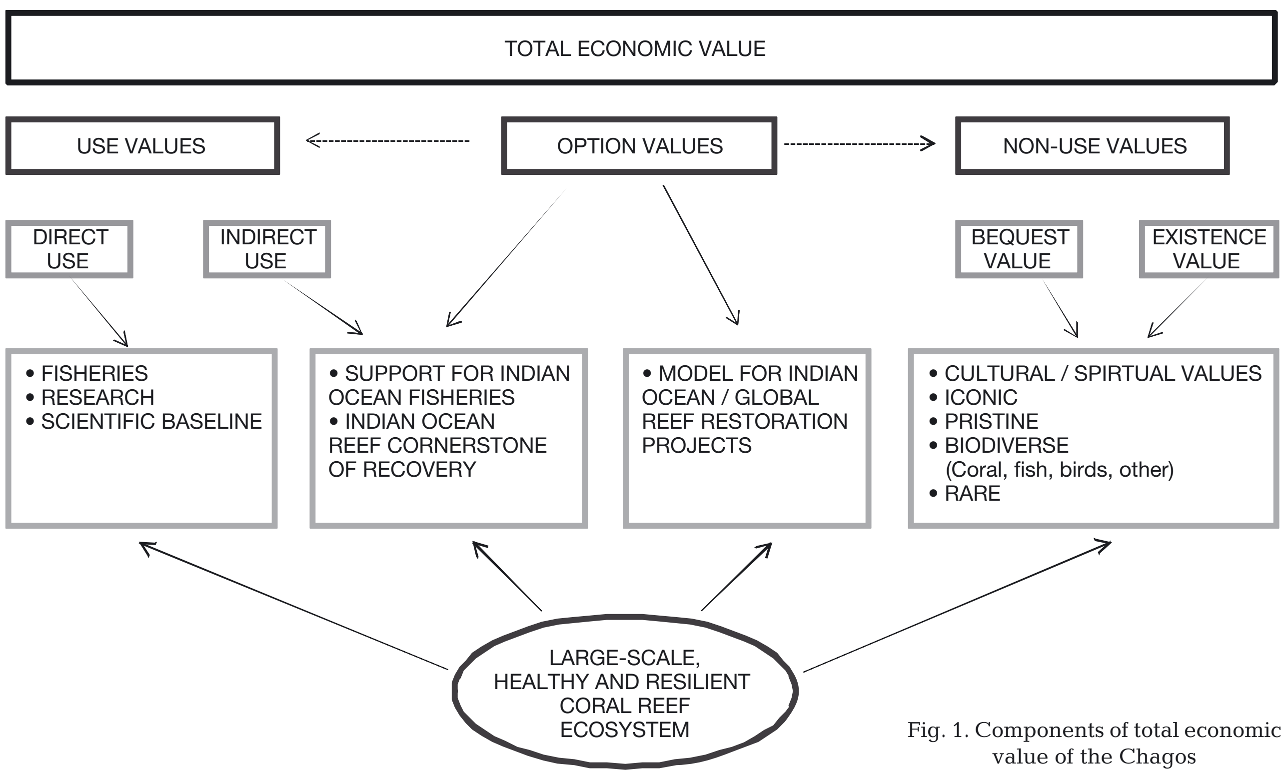

Fig. 1. Components of total economic value of the Chagos

world (Nelson & Bradner 2010). It is particularly challenging to value something for which there is not only no market but no good comparisons either

Together, uncertainty over some aspects of its ecosystem functions, the intangible nature of some of its benefits and the rarity of its combined characteristics, present considerable challenges in quantifying its economic value, potentially resulting in a material underestimation of its value.

Limitations of the TEV approach

Several conceptual issues regarding what value may be attributed to the Chagos lie beyond the scope of any TEV calculation.

The Chagos lies at the heart of the SWIO marine ecosystem (Sheppard et al. 2012) and possibly provides important long-term biological support to the economic well-being of many of the developing countries on its perimeter. While one might try to capture such support within the TEV framework as an indirect use value, this would also require a perspective on matters such as the contribution of this support to the gross domestic products (GDPs) of relevant countries, including the impact on employment, food supply or other social issues, and how to evaluate such contributions.

Also, many authorities regard economic value as only one measure of value within the broader meaning of the term. Value is an elastic notion which can encompass concepts such as 'community-based value', which reflects how society might assess tradeoffs beyond the level of any one individual, or even 'spiritual value' (US Environmental Protection Agency Science Advisory Board 2009). While one might with some ingenuity attempt to force such concepts into the TEV framework — for example, as a non-use or option value (see Markandya et al. 2008) — attempts actually to measure or estimate such values may prove extremely difficult.

With this in mind, the following analysis will attempt to present an open perspective of the value of the Chagos, including the possible contribution that the Chagos makes to adjacent marine ecosystems and their associated countries.

METHODS

Table 1 lists a number of identified ecosystem services categorised using the The Economics of Ecosystems and Biodiversity (TEEB) classification. Each

Table 1. Identified potential ecosystem services of the Chagos. NA: not applicable, SWIO: southwest Indian Ocean, WIO: western Indian Ocean

Ecosystem service	Ecosystem service typology (TEEB 2010)	Value type	Value subtype
Fisheries	Provisioning	Use	Direct
Shoreline protection	Regulating	Use	Indirect
Scientific value	Cultural	Use	Indirect
Support for SWIO fisheries	Habitat	Use	Indirect
Cornerstone of WIO reef recovery	Habitat	Use	Indirect
Model for Indian Ocean/global reef restoration projects	Cultural	Use	Indirect
Non-use benefits	Cultural	Non-use	NA

of these services encompasses a 'basket' of possible benefits which may be ascribed a monetary value. For example, the benefits attributed to fisheries might include not only an economically valuable fishery, but the as-yet unidentified cultural values associated with these fisheries. The nascent financial and scientific understanding of both the nature of the ecosystem services of the Chagos and their associated economic value makes 'bundling' of services the only viable approach in a preliminary study of this type. Ecosystem services include both final and intermediate services[1] — no fundamental distinction is being made here between the terms ecosystem service and ecosystem benefit.

The problem of incompleteness and inaccuracy in the data means that, in most cases, estimated value will be uncertain and may represent only one component of the total benefit. Estimated values have therefore been qualified with respect to the degree of certainty according to the scheme described in Table 2.

Most of the numbers resulting from this analysis will differ widely in terms of their methodological origin, degree of certainty, 'date stamp' and so on. Summing these figures in a naïve manner to estimate a TEV thus risks creating a number that might be convenient but without conveying the many flaws in its composition. Thus, the final part of this analysis will

[1]See Barbier et al. (2011) for a discussion of the conflation by some economists of the terms ecosystem services and benefits, and the Millenium Ecosystem Assessment (2005) for the definition of ecosystem services upon which this deliberation is based

Table 2. Scheme of certainty for estimated values

Category of value	Definition
Known	A value that is up to date, comprehensive and can be expressed with confidence
Partial	An incomplete valuation, i.e. considers only one facet of the economic value or is based upon a partial data set
Indicative	A value associated with high levels of uncertainty and/or limited relevance, e.g. a comparison with a site sharing only some similar characteristics
Unknown	No value will be given in cases where the benefit is not fully understood or where there is insufficient data to make an assessment

reflect upon a major study (TEEB 2009) which undertook a top-down estimate for the value of coral reef systems in general.

We make here a distinction between measures of 'flow' that refer to the economic product generated within one accounting period (such as a year), and measures of 'net present value' that represent the cumulative effect of flow items when summed into perpetuity using conventional discounting techniques.

In some instances, neither a measure of annual contribution nor net present value (NPV) has been estimated — particularly where data are either unreliable or absent. In these cases, the method adopted is discussed in conjunction with the relevant benefit. Table 3 shows the valuation approaches adopted (see Table 11 for a synopsis of the findings).

Table 3. Valuation approach used. SWIO: southwest Indian Ocean, WIO: western Indian Ocean

Ecosystem service/benefit	Valuation approach
Fisheries	Capitalised value of actual/ potential licence fees
Shoreline protection	Cost of installing 10 km of artificial breakwaters to replace reef services
Scientific value	Potential research value
Support for SWIO fisheries	SWIO gross fisheries output capitalised and apportioned
Cornerstone of WIO reef recovery	Not currently susceptible to analysis
Model for Indian Ocean/ global reef restoration projects	Not currently susceptible to analysis
Non-use benefits	Reference to non-use value of other reef systems

RESULTS AND DISCUSSION

Use values

Fisheries

Prior to 2010, there were 2 commercial fisheries in the Chagos — an inshore demersal fishery targeting snapper, emperor and grouper, and a pelagic purse-seine and long-line tuna fishery (Koldewey et al. 2010). Revenues from licence fees from the combined fisheries had grown at an average rate of 5% yr^{-1} over the decade preceding their closure, driven by growth in purse-seining. The inshore fisheries had generated negligible revenues while the long-line fisheries had experienced a falling catch and revenues (see Appendix for selected data on the Chagos fisheries).

Inshore fishery. A Mauritian fishery had operated inshore within the Chagos archipelago since at least the early 1900s (Mees et al. 1999), and, following the 1970s, it continued for several years at very low levels. This targeted primarily snapper, grouper and emperor operating on a controlled-effort basis with a maximum of six 80d licences issuable in a season running from April to October (Mees et al. 1999). Only hook-and-line fishing was permitted, with no fishing permitted within any of the lagoons. Licences for hook-and-line fishing were issued only at the discretion of BIOT and usually only to Mauritian-owned companies (C. C. Mees, pers. comm.).

Although the estimated maximum sustainable yield (MSY) of the fishery (all line-caught fish from intermediate depths) is 1782.5 tonnes yr^{-1} (Mees et al. 1999), the catch had been only a fraction of this for many years prior to the declaration of the MPA (Table 4), with a significant decline since 2004 (Mees et al. 2008).

Offshore fishery. The western Indian Ocean (WIO) covers 8% of the world's oceans but generates only 4% of the declared global industrial catch, of which roughly a quarter is tuna (van der Elst et al. 2005). BIOT makes up 6.5% of the WIO total. In 2008, just over £1 million was raised in licence fees, of which 60% was raised from purse-seine and 40% from long-line licences. Of the total catch, 76% comprised yellowfin tuna, with the remainder split roughly equally between skipjack and bigeye (Mees et al. 2008).

Valuation. Fisheries businesses can generally be valued in terms of their 'economic rent' — basically the difference between the cost of doing business and the revenues associated with it (Sumaila 2008b). This can be further analysed between the economic rent earned by the licensing authority and the profits attributable to the fishers themselves. Only the first of these is assessed here.

Unfortunately, information required to assess the costs of administering the fishery was deemed to be commercially sensitive and is unavailable. Costs include a contract fee paid to MRAG and a share of the running costs for a patrol vessel (the 'Marlin') which also undertakes other duties not directly related to the fishery. Thus, gross annual revenues (i.e. licence fees) might represent an important proxy for the local annual economic contribution of these fisheries.

The inshore fishery historically generated minimal income for BIOT. In the event that this fishery was functioning on commercial terms, it would be possible to envisage some moderate licence income. In Table 4, various parameters illustrate the potential annual licence fees that this type of fishery might generate.

Although increasingly challenged as a fishery management tool (e.g. Finley 2011), a key concept for valuing fisheries remains the MSY. This is the catch rate at which the productivity of the fishery is maximised while maintaining a stable population (and stable catch rates) into the future. Table 4 shows the calculation and underlying assumptions for the reef fishery. The estimated MSY for the inshore fishery is a number approaching 1800 tonnes yr^{-1}, with a potential landed value of £1666 $tonne^{-1}$. This gives rise to a total catch value at the MSY of approximately £3 million yr^{-1}. Applying a typical licence fee of 6% of catch value would imply a licence fee potential of approximately £180 000 yr^{-1}.

For the offshore fishery, the revenues of approximately £1 million that applied prior to MPA implementation have been taken as the maximum annual potential on the basis that pelagic fisheries are not expected to grow significantly over time (FAO data suggests total Western Indian Ocean fisheries landings peaked in 2006 at 4.2 million t [FAO 2014]). Increasing scarcity value for pelagic species might in time drive up the market price to the point where well-managed fisheries will be able to extract a greatly increased fee income, but such reasoning has not been applied here.

Most valuation techniques seek to quantify future economic benefits likely to arise from an environmental asset, including the profile of how they accrue over time. These future benefits may then be rendered into a single monetary value which reflects the sum of all future benefits adjusted to take into account the idea that more distant flows are worth less today than their nominal future value (Sumaila & Walters 2005). The process of adjusting future flows into their present-day equivalents (their 'present value') is called discounting (e.g. Penman & Sougiannis 1998, Sumaila 2004, Pearce et al. 2006). Because of the discounting procedure, the present value of a given financial benefit diminishes the further away it is in time. However, where a benefit is expected to increase over time, there will be some mitigation of the discounting effect. It is the balance between anticipated growth and discount rate that typically determines how a series of future financial flows translate into an overall cumulative value at the present time (Heal 1998).

It is beyond the scope of this paper to attempt a detailed discounted cash flow (DCF) exercise for the ecosystem goods and services being evaluated here because there is insufficient and often no data on

Table 4. Potential licence revenues from Chagos inshore fishery. MSY: maximum sustainable yield

Variable or parameter	Assumption		Value
Maximum sustainable yield	Estimated MSY of all line-caught fish to depths of 150 m (Mees et al. 1999)		1782.5 t yr^{-1}
Market price of landed catch	Estimated at £1666 t^{-1}. Based on £1250 t^{-1} for snapper, £1460 t^{-1} for emperor and £2450 t^{-1} for grouper and weighted for the structure of the catch (C. C. Mees pers. comm.)	×	£1666 t^{-1}
Annual revenue generated by the landed catch		≈	£3 million yr^{-1}
Licence fee structure	A margin of 6% payable on gross landed value of catch. This represents a typical rate paid on similar fisheries (species, region, etc.)	×	6%
Annual licence fee potential		≈	£180 000 yr^{-1}

present-day economic and financial inputs — let alone clarity on future flows. Rather, the approach taken is to illustrate the kind of outputs and sensitivities that may arise from a detailed DCF analysis using a formulation based on valuation multiples.

Valuation multiples are commonly used in financial markets (Lie & Lie 2002). They have the advantage of requiring less information than a tailored, asset-specific DCF (Damodaran 2012) and enable a range of possible outputs to be presented in a readily comprehensible manner.

Here we define 'the multiple' as the ratio of the total present value of a series of financial flows to the first flow in the series. A common starting point is to assume that both the growth rate and the discount rate are constant over time. In this simplified case, the present values of individual flows form a regular series that may be easily summed (Table 5).

Multiples in the 10× to 20× range can be generated using plausible underlying assumptions. This implies that the TEV of such a benefit provided in perpetuity might be 10 to 20 times the value of that benefit in a single year. Low growth rates have been used in Table 5, given the sensitive nature of the Chagos, while the discount rates illustrated would be consistent with discount rates typically observed in traded values of private enterprises (Pratt & Grabowski 2008). Many arguments may be had concerning the most appropriate discount rate for any given situation (Goulder & Stavins 2002). Table 5 could have been constructed to encompass a broader range of possibilities, including some where lower discount rates apply and where valuation multiples are correspondingly higher — and also scenarios where a future fishery collapse led to a truncation of future benefits, which would substantially reduce the effective multiple, potentially into single digits.

Based on assumptions given in Table 4 and the most recent revenues generated by the offshore fishery, the combined annual licence fee potential of the inshore and offshore fisheries may be of the order of £1.2 million, the vast majority of which would be generated by the offshore fishery. There is then a need to convert annual licence fee income into a measure of economic rent by deducting the costs involved in administering and enforcing the licence system. Since information regarding these costs is not available, the necessary adjustment has been implemented in Table 6 by applying a range of assumed revenue conversion factors. Low multiples have been proposed to reflect the intrinsic low growth of most fisheries and the possibility of future population collapse. It is also possible that administration and enforcement costs would be quite high in practice, implying a lower revenue conversion than shown and a reduced overall value. The results show a range of possible values based on these assumptions — from a present value of £3 million using a 5× multiple and a 50% conversion rate, to a present value of £18 million assuming a 15× multiple and a full conversion of revenues.

The offshore component of value is essentially a known value, accepting that it relies upon projections for future licence fee income and assumptions regarding discount rates and revenue conversion. The inshore component of value could be regarded as a partial value according to the scheme set out in Table 2, and would require the development of the fishery in the future such that it could generate the envisaged licensing income.

Shoreline protection

Healthy coral reefs provide natural protection to shorelines (Koch et al. 2009). They act as buffers, absorbing up to 90% or more of wave energy (Sheppard et al. 2005, UNEP-WCMC 2006). In the Chagos, reefs offer shoreline protection to 2 very different sets of beneficiaries. Although much of the value comes from marine resources, the islands are also of great consequence to terrestrial flora and fauna (10 of the islands have been designated Internationally Important Bird Areas [BirdLife International 2015], with another 2 proposed [McGowan et al. 2008]). The threatened coconut crab (Barnett et al. 1999) and

Table 5. Valuation multiples in a constant-growth and constant-discount-rate model

Discount rate	Growth rate 0%	1%	2%
6%	16.7	20.0	25.0
8%	12.5	14.3	16.7
10%	10.0	11.1	12.5

Table 6. Potential value of 'economic rent' derived from fisheries licence fees (£ million)

Multiple	Revenue conversion factor 50%	75%	100%
5×	3.0	4.5	6.0
10×	6.0	9.0	12.0
15×	9.0	13.5	18.0

green and hawksbill turtles (Mortimer & Broderick 1999) also breed on the islands. The other main beneficiary is, of course, the US naval facility on Diego Garcia.

Valuation. Economically, the value of this service is closely related to what the reefs are protecting. The higher the value of asset being protected, the greater the value of the service being provided. Shoreline protection may be valued not only in terms of what it is protecting (a revealed value), but also on the basis of what it would cost to replace the service, by reef restoration programmes perhaps, or by artificial means (van Beukering et al. 2007, Barbier 2014, Waite et al. 2014).

One consequence of this variety of approaches and data sources is the wide range of possible values for the shoreline protection services offered by the Chagos reefs. With respect to the naval facility, for example, it is impossible to estimate the value of the military base.

A reasonable approach is to focus on the cost of providing alternative means of shoreline protection and taking this estimate as a proxy for value (Cesar & van Beukering 2004, Cesar & Chong 2005). Two relevant examples exist. Firstly, work has been undertaken in Malé in the Maldives to install concrete tetrapods to protect that country's capital. This programme (which will have to be renewed periodically) cost US$10 million km^{-1} (Walser & Neumann 2008), equivalent to £6 million km^{-1} at current exchange rates. The second example is in Diego Garcia itself, where work done 2 decades later has cost the far higher sum of $10 million yr^{-1} to strengthen only 200 m of coast (Schwarzkopf 2012).

Table 7 illustrates a sensitivity analysis of the possible costs for the protection of shoreline around Diego Garcia using the much lower Malé example as the base case. Clearly, the number could be very substantial indeed. Given the uncertainties around such a calculation, the figures shown are best regarded as indicative values for remediating the loss of reef protection.

Table 7. Potential cost of replacing shoreline protection (£ million)

Cost km^{-1}	Shoreline protected		
	5 km	10 km	15 km
£4 million	20	40	60
£6 million	30	60	90
£8 million	40	80	120

Scientific value

Unlike most tropical shorelines, which typically support dense and rapidly growing human populations, the Chagos islands are exposed to only minimal human impacts. One of the most important implications of this preserved 'natural state' is the value of the Chagos to science. Not only does the Chagos provide the opportunity to understand a relatively undisturbed tropical ecosystem, but it offers a critical capability of acting as a scientific baseline or control site for similar systems around the world in the face of growing human impacts and threats. Pelagic fisheries (Koldewey et al. 2010, Sheppard et al. 2012, 2013), deepwater ecosystems (Sheppard et al. 2012, 2013) and Indian Ocean and global climate change research (Sheppard et al. 2012, 2013) have been cited as important scientific beneficiaries of a large functionally linked marine ecosystem. This is particularly true for a healthy and resilient integrated ecosystem, as is the case for the Chagos.

This value to scientific understanding is very difficult to quantify in monetary terms. There are no markets for this. Similarly, both global (e.g. Nordhaus & Popp 1997) and local (e.g. Koundouri et al. 2012) studies on the economic value of climate change research, for example, offer little or no insight into the values of the science derived from a location with such unusual characteristics.

One measure used in other studies to assess scientific value is to look at expenditures on scientific research in progress (Cesar & van Beukering 2004). While non-military research expenditure for BIOT is thought to average roughly £150 000 yr^{-1} for the period 2006–2010 (C. R. C. Sheppard pers. obs.), this is not likely to be a fruitful avenue for evaluating the profound potential utility of a site such as the Chagos.

Possibly the greatest global scientific contribution that the Chagos is able to make in this respect is related to global climate change studies. However, quantifying that research value at this stage seems intractable, so no defensible estimate of value can be proposed in this report, although the value may well be considerable.

Role of the Chagos in supporting SWIO fisheries

Some of the most important scientific work done on the Chagos in recent years has been to look at its role as a stepping stone in the predominantly east–west flow of species across the SWIO. Studies on a range of species, including the hawksbill turtle *Eretmochelys* *imbricata* (Mortimer & Broderick 1999), snapping shrimp (numerous species) (Williams et al. 1999), crown-of-thorns starfish *Acanthaster planci* (Vogler et al. 2012), various fish species (Craig 2008, Eble et al. 2011), the coconut crab *Birgus latro* (Sheppard et al. 2012) and coral (Sheppard 1999, Obura 2012), indicate that the Chagos is an important biological crossroad in the Indian Ocean (Wilkinson et al. 2008, Sheppard et al. 2012, 2013), acting as a stepping stone between the eastern and western sides.

Implicit in this relationship is its possible role in supporting the fisheries and other biodiversity in the area. At the most basic level, ascribing a role for the Chagos in supporting the surrounding fisheries would imply an economic value for the Chagos that relates to the value of all of the relevant fisheries. However, uncertainty over the ecological links between the Chagos and its associated marine ecosystems means it is not feasible to quantify with any precision an economic value for the Chagos in relation to these fisheries. What may be more meaningful would be to describe the fisheries of the SWIO large marine ecosystem (LME) and the various dimensions of their economic significance for the area. Fundamental to this approach is the premise that the medium- and long-term health of the area underpins their economic productivity. The Chagos may in turn provide crucial services in sustaining the long-term health of this marine ecosystem.

Contribution of SWIO fisheries to poverty alleviation, food security and growth. The SWIO is bordered by and contains within its waters some of the poorest countries in the world. It is well understood that natural resources are often most valuable to the poor, who have few alternatives and who suffer most when such 'free' natural services are lost or degraded (Markandya et al. 2008). For coastal nations, the marine environment is a natural asset of great importance (GEF 2006). The following analysis considers how the SWIO fisheries contribute to food security, employment and GDP in a region facing severe and, in some instances, growing socioeconomic challenges.

The SWIO region. A number of populous countries lie in the SWIO region, and are home to around 110 million people, of which roughly half reside within 60 km of the coast (Kimani et al. 2009). Many cities are expected to double in size over the next 25 yr (GEF 2006). The WIO is highly diverse, and is a distinct biogeographical province with >10 000 species of marine fish and invertebrates in several zones with exceptionally high levels of endemism (GEF 2006). The area is one of the world's most biologically valuable ecoregions (Olson & Dinerstein 1998).

SWIO fisheries. The commercial sector includes fisheries for tunas and tuna-like species that are mostly operated by foreign fishing fleets (van der Elst et al. 2009). Several countries in the region offer licensing rights to distant-water fishing fleets also (GEF 2006). Countries in the region generally do not maximise the exploitation of their pelagic resources to their own benefit (Kimani et al. 2009, van der Elst et al. 2009).

Fish production in the SWIO was 532 000 t in 2006, constituting 5% of total Indian Ocean catch (FAO 2006), a figure that is a considerable underestimation because a large proportion of the subsistence catch is unreported — by a factor of up to 5× in the case of Mozambique (Kimani et al. 2009) — and unrecorded industrial catch is also substantial. This lack of data is mirrored by a similar deficiency in terms of fishery status, although the FAO is of the opinion that the WIO and parts of the Pacific are the only regions in the world where there remain fish stocks with potential for further exploitation (FAO 2006), though equally, its studies indicate that artisanal fisheries in the WIO already exploit 75% of fisheries to their maximum biological productivity whilst the remaining 25% are over-exploited.

The economic contribution of fisheries to the SWIO economy has several different aspects. Foremost is food security. It is impossible to overstate the importance of this (Walmsley et al. 2006), as fish is a major part of the diet of coastal populations in many of the countries concerned, ranging from a few percent of total animal protein consumed in the case of the East African countries to around half or more for the Seychelles, Mozambique, Comoros and Maldives (Kimani et al. 2009). Secondly, coupled with this, are livelihoods. The majority of coastal fisheries in the region are artisanal (van der Elst 2005). Although they are not a major source of income to participants, they provide an important source of employment and broader social provision (GEF 2006). Studies have suggested that there are up to 400 000 fishers on the east coast of Africa and Madagascar. Applying an estimated dependency ratio of 7:1 (1 fisher supporting an additional 6 individuals) would imply that approximately 3 million people are directly dependent upon marine fisheries in the area (van der Elst 2005).

Thirdly, national income is generated. Table 8 shows the gross value of marine fisheries in the SWIO along with estimates of their contribution to GDP. What these figures conceal is the importance of fisheries as a source of foreign exchange. For Mauritius, Mozambique and Madagascar, even

Table 8. Gross value of fisheries outputs for southwest Indian Ocean nations (South West Indian Ocean Fisheries Commission 2006). GDP: gross domestic product

Country	Gross value of fisheries output (US$ million)	Year	Gross value of fisheries output (% of GDP)
Comoros	39[a]	1999	15
Kenya	4	1997	5
Madagascar	160	2001	4
Maldives	35	1996	11
Mauritius	106	2004	1
Mozambique	72	2001	1
Seychelles	212	2003	30
Somalia	55	2001	2
South Africa	404[b]	2003	1
Tanzania	325	2005	9
Yemen	125	1999	15
Total	**1237**		

[a]Gross value of landing (ex-vessel prices)
[b]Wholesale value

though fisheries contribute only a small percent to GDP, they provide up to 40% or more of foreign exchange earnings (Kimani et al. 2009). Foreign exchange is earned not just from exports but from providing fisheries services to producers in the region: in the Seychelles, for example, >30% of its foreign exchange earnings are fisheries-related (GEF 2006, Kimani et al. 2009).

Although the data shown in Table 8 is reported by the South West Indian Ocean Fisheries Commission (2006) and is derived from the most up-to-date FAO Fisheries Fact Sheets, some of it appears to be very out of date and as such is likely to under-represent the current value of the fisheries.

Valuation. It is apparent that fisheries make an additional contribution to the economic welfare of the countries in the region (Walmsley et al. 2006) beyond supplying vital nutrition, although the scale of contribution is likely to vary considerably by country. For some of these countries, fisheries are clearly central to national economic productivity. They provide income and employment in an area where there are very few or no alternatives (Béné et al. 2007, Pomeroy & Andrew 2011). This is particularly the case for reef-fishers and their dependents, often singled out as being amongst the 'poorest of the poor' (Whittingham et al. 2003). In a region facing high population growth, a dependency on primary industry, growing environmental stress levels and unremitting health problems where >50% of child mortality is caused by malnutrition (Black et al. 2003, Bryce et al. 2005), marine fisheries represent a vital contribution to national social and economic well-being (van der Elst et al. 2009). In such circumstances, the benefits of MPAs in providing economic benefits to their surrounding areas are firmly established (Leisher & Larsen 2010).

Table 9. Sensitivity of Chagos indirect use value based on southwest Indian Ocean (SWIO) fisheries revenues (£ million)

Multiple	Proportion of SWIO fisheries gross value attributable to the Chagos				
	5%	10%	15%	20%	25%
6×	225	450	675	900	1125
9×	338	675	1013	1350	1688
12×	450	900	1350	1800	2250
15×	563	1125	1688	2250	2813
18×	675	1350	2025	2700	3375

It would be tempting, in pursuit of a conservation agenda, to put forward the sustained health of the Chagos ecosystem as the sine qua non of the SWIO fisheries, but such a claim would be highly premature. Although some benefits appear increasingly likely and the precautionary principle should apply, further work is required to understand the interactions taking place within the SWIO LME and the extent to which degradation of the Chagos might impact the health of the SWIO fisheries. As these linkages are established, it will become necessary to understand what proportion of the fisheries value can be attributed to the Chagos as an indirect-use value. In Table 9, some value sensitivities are shown based on the gross fisheries value of US$1237 million that was shown in Table 8, equivalent to £750 million at current exchange rates. The multiples used in this table follow the scheme already discussed above, with a possible argument that lower multiples are appropriate for fisheries if there is a risk of collapse and truncation of benefit.

The Chagos as a cornerstone of WIO reef recovery

An important, but as yet hypothetical and possibly immeasurable, benefit of the Chagos, is the future role it may play in the recovery of WIO reefs. This hypothesis asserts that if WIO reefs (excluding the Chagos) were unable to survive the anthropogenic threats (and in particular climate change) forecast for the coming decades, the Chagos could act as a refuge for a wide range of marine species for at least a few decades beyond the time predicted for the collapse of densely populated reef areas.

For the Chagos to fulfil this role, it would need to be linked with the WIO in such a way that it could re-stock western marine ecosystems — a function that is assumed in the Chagos' present support for SWIO fisheries. It is relatively resilient to climate change effects at present because of the lack of local impacts, and although the Chagos was very badly affected by the bleaching that impacted coral reefs throughout the region in 1998, its reefs have recovered more extensively and faster than any other known coral reef system in the Indian Ocean, demonstrating in this and other measures considerably greater robustness and resilience (Sheppard et al. 2008, 2012, 2013, Wilkinson et al. 2008, Graham & McClanahan 2013). The rebound of the Chagos' reefs following the temperature spikes of the 1990s suggests that, with good maintenance, they may be able to survive for as much as 20–30 yr longer than most of those in the region (Harris & Sheppard 2008, Sheppard et al. 2008).

The natural replenishment of WIO reefs is not the only way in which the Chagos may be able to provide a biological aid to the restoration of regional marine ecosystems. It is well known that the Chagos has very little marine endemism (Sheppard 2000), perhaps because it acts as a stepping stone or thoroughfare, and so may potentially provide an *in situ* population of some reef species that can be used to re-stock other areas by artificial means. Sea cucumbers (holothurians), an important coral reef keystone species, which have been badly impacted by illegal poaching across the Indian Ocean, including Chagos (Price et al. 2010, 2013), have been suggested as a suitable candidate for re-stocking (C. M. Roberts pers. comm.).

Related to these potential biological roles in aiding WIO reef recovery is a more practical, management one. If the Chagos were to survive as an outpost of high-quality reef in the WIO, it would provide an extensive example of coral reef devoid of a range of anthropogenic impacts such as industrial and sewage pollution, shoreline construction and destabilisation and dredging, and as such could provide marine managers with a model upon which to base their own local restoration efforts.

Valuation. Both of the benefits discussed above — biological and management — currently have only an option value, i.e. they relate only to a possible future use.

The potential economic benefit of the Chagos as a broad-scale aid to WIO reef recovery may be incalculable for the foreseeable future. First (and most obviously), the exact nature of the biological links between the Chagos and the rest of the WIO are not yet fully understood. In particular, the timescales over which these linkages may function — whether they operate over years, decades or millennia — is uncertain in most (but not all) cases. Early information suggests that for some species such as the endangered coconut crab, the Chagos is an effective reservoir for the WIO that is interconnected in ecologically meaningful time scales (Sheppard et al. 2013). The value of the benefits provided by the Chagos here is ultimately determined by the value of the reefs potentially supported by it. Under a scenario of widespread loss of coral reef ecosystems across the WIO, these values need urgent investigation.

For related reasons, there is insufficient understanding today of the benefits that the Chagos might provide by preserving a standing stock of some marine species or in acting as a management aid to reef restoration in order to facilitate an estimation of the value of these potential benefits.

Our inability to calculate an economic value for an ecosystem good or service does not mean it does not have one. The TEEB Project, an international coalition of governments, non-governmental organisations and academicians, released a 'Climate issues update' considering the economic value of coral reefs (TEEB 2009). One of the key points it raised is that as global coral reef systems come ever closer to complete collapse, traditional methods of valuing them will become irrelevant. When an entire ecosystem reaches the threshold of irreversible collapse, its scarcity value will result in an entirely new quantum of value. If such a point is ever reached for the world's oceans — which on current trajectories may occur within a matter of decades — the Chagos may become the last remaining significant coral reef system in the WIO, conferring upon it immense significance and value.

Non-use values

The Chagos is a stronghold of Indian Ocean biodiversity, both terrestrial and marine. It is home to perhaps 1000 species of fish and at least 220 species of coral, and is a refuge and breeding ground for large and important populations of megafauna (Sheppard et al. 1999). In addition, the deep oceanic waters around the Chagos Islands out to the 200 nautical miles (370 km) Fisheries Conservation Management Zone (FCMZ) include an exceptional diversity of undersea geological features (Clark et al. 2006, Yesson et al. 2012), almost certainly in an undisturbed condition (Sheppard et al. 2012). In marine terms, BIOT is by far the most biodiverse part of the UK and its Overseas

Territories (Sheppard et al. 2009). The Chagos is also extraordinarily rich in avian biodiversity (Carr 2011).

The unspoiled state of the Chagos is well documented. An absence of anthropogenic influences has ensured that the coastal reef waters of the Chagos are amongst the cleanest in the world (Guitart et al. 2007, Readman et al. 2013), and are home to >25% of the reefs under lowest threat in the Indian Ocean (Burke et al. 2011). They are also by far the largest contiguous reef tracks considered to be under low threat in the world (M. Spalding pers. comm.).

The diversity and condition of the natural resources of the Chagos, combined with its scale (totalling over 640000 km^2), make it unique in the Indian Ocean and one of only a handful of similar sites in the world (Nelson & Bradner 2010). Although virtually unknown in the west, it does not seem to be in any way an exaggeration to refer to it as 'iconic' — and as such of potentially enormous existence and bequest value both to the Chagossians, but to other communities around the world.

Valuation

For biodiversity, a distinction needs to be made between use and non-use values. Use values — mostly indirect — have been included implicitly in the goods and services already discussed, such as the support the Chagos provides to Indian Ocean fisheries. Non-use values are distinct from these.

There are 2 major challenges in valuing the Chagos as a 'marine icon' over and above all the well-known difficulties in valuing something for which there is no market. The first is the lack of analyses to use for comparative valuation purposes. Non-use valuations for marine resources are very scarce (Hargreaves-Allen 2004), and NOAA takes the view that to date there are no meaningful non-use studies of coral reef ecosystems (V. R. Leeworthy pers. comm.). The difficulties associated with valuing non-use benefits have been a successful deterrent in attempting such exercises, notwithstanding the fact that there is weighty evidence that non-use values can make up a very large proportion of the economic value of biodiversity, even as much as 99% of the total value (Jacobs et al. 2004).

Another reason for the lack of suitable reference material is that the non-use valuations that do exist are generally non-transferable between sites. So-called 'choice modelling', whereby respondents are asked to rank their preferences in relation to the benefit in question as opposed to articulating a discrete value for it (Hanley et al. 2001), especially may not be transferable. The absence of useful reference material is particularly pronounced in relation to the Chagos — a high-quality marine asset with few comparisons.

A second challenge relates to the question of to whom the Chagos has worth. Outside the WIO, the Chagos is almost completely unheard of. Does the non-use value of the Chagos depend on how many people know that it exists or does its non-use value somehow transcend this lack of awareness? How would different groups of people differ in the value they place on its non-use? Is the relevant population limited to the region, to those living in the WIO, or does it extend to the British taxpayers who are currently responsible for its governance, and ultimately the global community?

As one of only a tiny number of such sites left in the world, it would seem intuitive that the case for preserving the Chagos would attract broad support. However, the challenges of communicating such a choice are immense, and the likely differences in opinion across different cultural groups are obvious, as one sees from the global debate regarding climate change.

The value of Chagos coral reefs: a global comparison

While it is the case that marine ecosystems are generally heavily under-represented in biodiversity valuation literature (Balmford et al. 2008), a number of studies of the value of coral reefs have been undertaken, with a small number of meta-analyses that attempt to synthesise these findings on a global level. Any attempt to transfer the findings of these studies to a valuation of the Chagos risks ignoring its special characteristics. Not enough is known about the nature of the goods and services provided by the Chagos, and it has some unique characteristics that make comparisons difficult.

These limitations notwithstanding, these meta-analyses and the underlying research invariably conclude, regardless of the site-specifics, that coral reefs have considerable economic value.

Table 10 shows the findings of a meta-analysis of coral reef values. The general approach is to assess the value of the services provided by the respective coral reef systems on the basis of their value per unit area. It should be noted that the figures shown represent the annual value of the services provided.

The average value contribution is estimated by the TEEB (2009) study at roughly \$129000 ha^{-1} yr^{-1}.

Table 10. Benefits from ecosystem services in coral reef ecosystems (TEEB 2009). Estimates are based on an ongoing analysis for The Economics of Ecosystems and Biodiversity (TEEB) project. As the TEEB data and value analysis are still under development, this table is for illustrative purposes only

Ecosystem service	Value (US$ ha^{-1} yr^{-1}, 2007 values) Average	Maximum	No. of studies
Provisioning services			
Food	470	3818	22
Raw materials	400	1990	5
Ornamental resources	264	347	3
Regulating services			
Climate regulation	648	648	3
Moderation of extreme events	25 200	34 408	9
Waste treatment/water purification	42	81	2
Biological control	4	7	2
Cultural services			
Aesthetic information/amenity	7425	27 484	4
Opportunities for recreation and tourism	79 099	1 063 946	29
Information for cognitive development	2154	6461	4
Supporting services			
Maintenance of genetic diversity	13 541	57 133	7
Total	**129 245**	**1 196 323**	**90**

Roughly two-thirds of this figure may be attributable to cultural services — the bulk of which comprises recreation and tourism. This component is largely irrelevant for the Chagos. A further fifth of this same study relates to 'moderation of extreme events', which refer to services such as shoreline protection from tropical storms, tsunamis and the like, with reference to the value of the real estate protected. With the exception of protection of the military base at Diego Garcia, this function is also less relevant for the Chagos.

If these 2 items are excluded, the residual annual value contribution would be nearer \$15 000 ha^{-1} yr^{-1}, equivalent to £9000 ha^{-1} yr^{-1} at current exchange rates. If this reduced figure were applied to the 900 000 ha (equivalent to 9000 km^2) of the Chagos' reefs (without related shallow sandy areas), it would still represent an impressive figure — nearly £8.5 billion (£8.5 × 10^9) — for the annual value of the ecosystem services provided.

SUMMARY AND CONCLUSIONS

When this analysis was undertaken (immediately prior to the creation of the MPA in 2010), the Chagos had a wide range of identifiable economic benefits. Few of them were associated directly with a market — the majority were intangible, providing diffuse benefits across the region and beyond.

Although the study relates to the Chagos prior to the creation of the MPA in 2010, the distribution of the benefits of the ecosystem goods and services identified were typical of a protected area (Balmford & Whitten 2003). The most tangible benefits were those that accrued locally. Benefits increase in their intangibility and difficulty in valuation as one moves away from the site.

Table 11 summarises the findings of the study, noting the benefit, its estimated economic value where any can be provided, geographical distribution of the benefit and prospective relative value. Although this preliminary review has not been able to quantify some of the economic benefits of these goods and services, their relative magnitude and potential importance were evident. It is clear that the abundant biological values of the Chagos were potentially accompanied by economic benefits on a global scale.

The content of this study was determined and limited by the current availability of data — both scientific and economic. In coming years, a more in-depth analysis of the Chagos (now an MPA), with greater data-gathering potential, could prioritise areas for further investigation.

It is probable that the time and resources required for filling in some of the data gaps and undertaking an in-depth study would be considerable. Understanding the role the Chagos MPA plays in WIO fisheries, for example — a context-specific ecosystem service not readily amenable to transfer analysis — will take many years, as studies relating to a greater range of species, including commercial stocks, are undertaken and published.

In the meantime, it is interesting to consider Bateman et al.'s (2011, p. 209) alternative strategy to managing uncertainty in ecosystem goods and service valuations: '… to infer value relationships based upon economic theory and related intuition.'

Although Bateman et al. (2011) were using the example of understanding how marginal changes in ecosystems affect their value, one might use their strategy to fill in a number of information gaps relating to the Chagos. As one of the last remaining 'super-wildernesses' left on earth, whether terrestrial or marine, the Chagos might — intuitively — be priceless.

Table 11. Summary of value components for the Chagos. SWIO: southwest Indian Ocean, TEV: total economic value, WIO: western Indian Ocean. Billion : £10^9, >: greater than, >>: much greater than, •: limited, ••: significant, •••: substantial, ••••: considerable

Ecosystem service/ benefit	Type of eco-system service/ benefit	Annual economic flow	Estimated TEV	Remediation costs or other factors to be considered	Knowledge qualifier	Valuation approach	Distribution of benefit	Potential value on relative scale
Fisheries	Use (direct)	£1.2 million	£9.0 million (range: £3–18 million)	–	Known/ partial	Capitalised value of actual/ potential licence income	Local to global	••
Shoreline protection	Use (indirect)	–	–	£60 million	Partial	Cost of installing 10 km of artificial breakwaters to replace reef services	Local	•
Scientific value	Use (indirect)	Averaging £100 000 yr^{-1} (2006–2010)	Hard to estimate	–	Unknown	Potential research value	Global	••
Support for SWIO fisheries	Use (indirect)	£750 million	Potentially >£1 billion	Significant support for SWIO economies and populations	Indicative	SWIO gross fisheries output capitalised and apportioned	Regional	•••
Cornerstone of WIO reef recovery	Use (indirect)	–	Potentially >>£1 billion	–	Unknown	Not currently susceptible to analysis	Regional to global	•••
Model for Indian Ocean/ global reef restoration projects	Use (indirect)	–	–	–	Unknown	Not currently susceptible to analysis	Regional to global	••
Non-use benefits	Non-use	–	Hard to estimate	–	Unknown	Reference to non-use value of other reef systems	Global	••••

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Appendix. Selected data for the Chagos fisheries. Source: UK national reports to IOTC (Pearce & Kirkwood 2004, Mees et al. 2008) and MRAG. Year classifications relate to fiscal years. CPUE: catch per unit effort; –: nil (revenues or catch)

	2000	2001	2002	2003	2004	2005	2006	2007	2008
Inshore fishery									
Catch (t)	122	289	219	219	237	128	–	136	119
Licence fees (£)	–	–	–	–	–	–	–	6000	780
Long-line offshore fishery									
No. of vessels	49	64	36	37	38	33	24	26	41
No. of licences	62	91	49	51	54	48	27	34	75
Days fished	1661	2052	901	1379	1060	664	1207	1147	1508
Total catch (t)	1939	1828	1034	1467	1162	730	916	590	1366
Licence fees (£)	342208	438756	315759	266536	285808	258033	162564	170463	349623
Purse-seine offshore fishery									
No. of vessels	17	48	50	52	52	52	54	55	54
No. of licences	19	48	50	54	53	56	56	56	57
Days fished	122	109	379	62	104	991	394	27	1294
Total catch (t)	3145	1064	5795	722	1320	23535	13865	95	23418
Licence fees (£)	356606	427171	536877	350134	250486	424637	526500	671400	680500
Productivity metrics for offshore fisheries									
Long line									
Catch per vessel (t)	39.6	28.6	28.7	39.6	30.6	22.1	38.2	22.7	33.3
CPUE (t d^{-1})	1.2	0.9	1.1	1.1	1.1	1.1	0.8	0.5	0.9
CPUE (t 1000 $hooks^{-1}$)	0.39	0.30	0.38	0.40	0.41	0.41	0.28	0.20	0.31
Purse seine									
Catch per vessel (t)	185.0	22.2	115.9	13.9	25.4	452.6	256.8	1.7	433.7
CPUE (t d^{-1})	25.8	9.8	15.3	11.6	12.7	23.8	36.2	3.5	18.1
Licence fee metrics for offshore fisheries									
Long line									
Avg. fee per licence (£)	5519	4821	6444	5226	5293	5376	6021	5014	4662
Effective fee d^{-1} (£)	206	214	350	193	270	389	135	149	232
Effective fee t^{-1} (£)	176	240	305	182	246	353	177	289	256
Purse seine									
Avg. fee per licence (£)	18769	8899	10738	6484	4726	7583	9402	11989	11939
Effective fee d^{-1} (£)	2923	3919	1417	5647	2409	428	1336	24867	526
Effective fee t^{-1} (£)	113	401	93	485	190	18	38	7067	29

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