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Ecosystem services "on the move" as a nature-based solution for financing the Global Biodiversity Framework

Ana M. M. Sequeira[1,2] ✉, U. Rashid Sumaila[3] & Abbie A. Rogers[4]

The Kunming-Montreal Global Biodiversity Framework (GBF) aims to halt global biodiversity loss. However, its implementation process will need strategic financing particularly to address the divide between the Global North and Global South. Highly migratory marine vertebrates (henceforth marine megafauna) connect distant ecosystems providing ecosystem services across jurisdictions with considerably different conservation interests and economic ability to pay for biodiversity protection. Although such migratory behaviour presents a specially challenging case for protection, because it provides a direct link between developed and less-developed countries it can provide a key to unlock the potential for financial support for implementing the GBF and shed light on a nature-based solution for how Official Development Assistance (ODA) could be deployed. Such ODA could ensure the global protection of these charismatic and threatened species, while contributing to the financing of the GBF. Our work emphasises the economic value of marine megafauna ecosystem services provided "on the move" across jurisdictions and highlights the economic value of conserving marine megafauna, our global heritage.

The value of marine megafauna and their contribution to the global economy

Urgent policy action is required to achieve the Sustainable Development Goals of the United Nations, and to resolve the current biodiversity crisis, as recognised by the Kunming-Montreal Global Biodiversity Framework (GBF; cbd.int/cop1,2; adopted 19th December 2022). In addition to halting global biodiversity loss (Goal A), the GBF aims to provide adequate means for its implementation by 2030 (Goal D). This ambitious goal focuses on increasing financial resources across all Parties to at least $30 billion per year by 2030, including through the use of Official Development Assistance (ODA) from developed to developing countries and States (Target 19). The GBF also seeks to ensure the effective management and use of wild marine species to provide benefits through sustainable biodiversity-based activities, products and services (Target 9).

Highly mobile or migratory marine vertebrates, including marine mammals, reptiles, fish and seabirds (such as whales, seals, turtles, sharks and penguins) - henceforth, marine megafauna, provide large benefits through sustainable biodiversity-based services, such as eco-tourism[1], but also include species of high economic value in extractive activities, such as fisheries[2] or caught as by-catch. Unsustainable uses and lack of appropriate protection to date, have led to a third of marine megafauna being now threatened with extinction (iucnredlist.org). Indeed, conservation of marine megafauna is particularly challenging because most species have k-selected life-history patterns that include slow growth and late maturity[2] and many are predominantly migratory, apex predators able to travel 1000 s of km annually connecting distant ecosystems across multiple jurisdictions[3]. Such migratory behaviour means that the area-based protection targets, such as those set out by the GBF aiming to protect 30% of the ocean by 2030 are likely to offer insufficient protection. However, many marine megafauna provide key structural, functional and cultural services within marine ecosystems[4,5], including acting as ecosystem and climate sentinels[6], exerting top-down control, playing important roles in nutrient distribution, affecting food chains and nutrient cycles[7,8], and creating opportunity for tourism, education and cultural connection[1]. Actions to conserve marine megafauna species and their migratory behaviour have the potential to be a nature-based solution that addresses a major current societal challenge while 'simultaneously providing human well-being and biodiversity benefits' (as defined by the International Union for Conservation of Nature; IUCN)[9]. Therefore, and particularly with the array of services they provide, it is important to understand how marine megafauna species connect different jurisdictions,

[1]Division of Ecology and Evolution, Research School of Biology, The Australian National University, Canberra, ACT, Australia. [2]UWA Oceans Institute and School of Biological Sciences, The University of Western Australia, Perth, WA, Australia. [3]Fisheries Economics Research Unit, Institute for the Oceans and Fisheries and the School of Public Policy and Global Affairs, University of British Columbia, Vancouver, BC, Canada. [4]Centre for Environmental Economics and Policy, School of Agriculture and Environment, Oceans Institute, University of Western Australia, Crawley, WA, Australia. ✉e-mail: ana.sequeira@anu.edu.au

where do they offer the provision of different services, and what is the value attributed to each of those services in different locations (Fig. 1).

Quantification of the value of marine megafauna services through existing economic frameworks, such as 'Total Economic Value' (TEV)[10], would allow for identification and prioritisation of which services are highly valued in different locations, and also which of those might be conflicting or complementary. Specifically focusing on the mobile nature of these species, we propose that the identification of marine megafauna values could shed light on the economic value of the ecosystem services they generate and on how this value can be compensated to best support the GBF through sources such as ODA. Such innovative perspective of the economic value of marine megafauna would ensure global protection of charismatic and threatened marine megafauna species while the funds generated could be used to achieve the goals of the GBF. We emphasise that due to the immense economic value generated by marine megafauna, their global conservation can be economically advantageous through the net benefits they generate for the countries involved and the world at large.

Understanding ecosystem services 'on the move'

The spatio-temporal variability of ecosystem services is defined in the literature as ecosystem services flows, particularly when looking at differences and mismatches between where an ecosystem service is supplied and where it is demanded[11], or as 'telecoupling', i.e., as the socio-economic and environmental interactions that take place between different places that can be separated by distance[12]. Such ecosystem services flows are often defined based on the specific indicators that describe the relative contributions biophysical or socio-economic attributes, on the identification of the supply and receiving (or beneficiary) systems, on their direction and branching, and on the spatial and temporal scales at which they occur[13]. However, the concept we are presenting differs from those definitions, as our focus in on the producer of ecosystem services (rather than the beneficiaries) and on a type of ecosystem service that is continuous and itself moves and adapts (i.e., adds services) depending on the location where the producer travels through.

Marine megafauna movements across the global ocean results in the 'delivery' of a range of ecosystem services provided across multiple jurisdictions and human communities. These include the provision of regulating services, which are associated with the way many marine megafauna species balance the ecosystems through top-down control. Examples of such services include control of meso-predator release[14,15] and of overfeeding by herbivores[16], provision of carbon sequestration services[8,17] and promotion of nutrient cycling, as well as transportation of nutrients between ecosystems or across depths, e.g., from the deep scattering layers to the surface[18]. Although these services are of value across the geographical ranges of marine megafauna, other services also provided by marine megafauna are of different value to different communities. These other valued services often derive from direct extractive uses, including artisanal or commercial fishing, which may deliver a direct market value or may be related with subsistence fishing, such as the indigenous whale hunting[19]. However, marine megafauna value can also derive from direct non-extractive uses. These include value from eco-tourism, which may deliver a direct market value, or contribute value through recreational use. The latter can be described as use-related non-market value, particularly for public or individual-led recreation opportunities, but also indirect market-based value through their support of related industries, such as enterprises who supply scuba diving gear or rent out other aquatic equipment. Additionally, marine megafauna also deliver non-use values, such as those generated from the knowledge that marine megafauna species exist, or those associated with the cultural connections to marine megafauna as totem species. All these non-market values contribute positively to the well-being of communities despite not generating a financial (market-valued) benefit. The combination of such ecosystem services provided by marine megafauna "on the move" across multiple jurisdictions and across communities can be summed to estimate the total value of marine megafauna across different market and non-market categories to highlight how much their conservation is worth (see Example in Box 1). Some quantification of ecosystem services provided by migratory species has been done through operationalisation of the telecoupling concept to calculate spatial subsidies[20]. Although this 'spatial subsidies' approach provides a good framework to understand how locations are coupled to each other based on the ecosystem services they need, a new approach that takes into consideration the negative effects on the producer (e.g., impacts on marine megafauna) needs to be added to the spatial subsidies calculations. This is needed to correctly account for

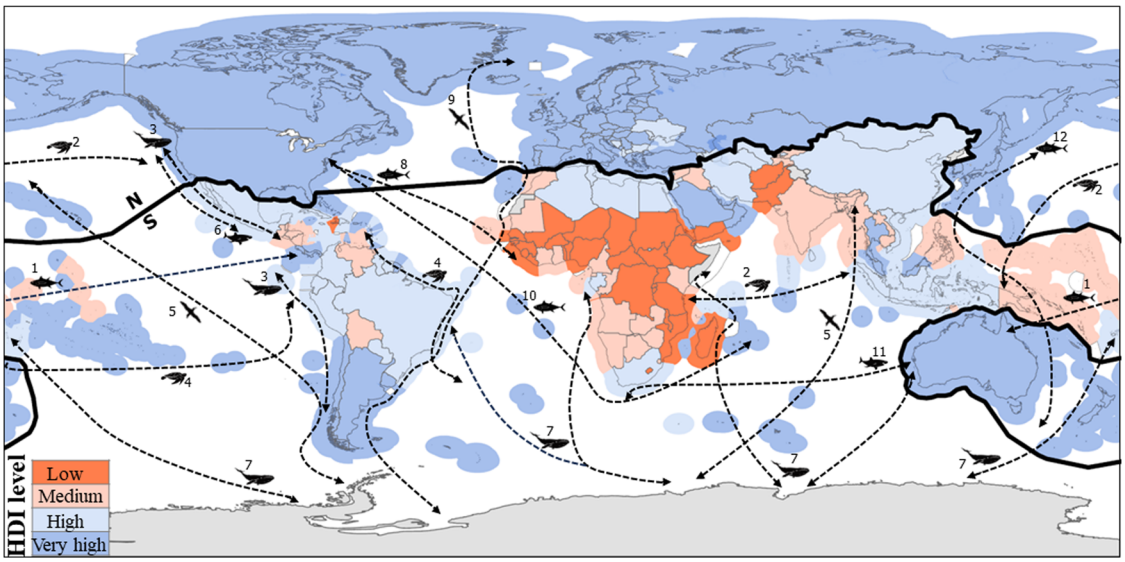


Fig. 1 | Examples of known animal migrations (dashed lines) connecting far-apart, highly- and less-developed countries and jurisdictions across the Global North and Global South. Dashed line with arrows represents known movement paths used by different highly migratory marine species. Countries and their respective exclusive economic zones (EEZs) were obtained through https://www.iucnredlist.org/resources/spatialtoolsanddata and https://www.marineregions.org/downloads.php (accessed 06 Dec 23). Colour code reflects the Human Development Index (HDI) in 2021 (https://hdr.undp.org/data-center/human-development-index#/indicies/HDI; accessed 06 Dec 23). The solid black line represents the division between Global North and Global South. (1) Black marlin[30]; (2) Leatherback turtle (seaturtlestatus.org/swot-report-vol-18); (3) Blue whale[31]; (4) Loggerhead turtle[32]; (5) South polar skua[33]; (6) Mako shark[34]; (7) Humpback whale[31,32]; (8) White marlin[30], (9) Arctic tern[30], (10) Blue marlin[30], (11) White Shark[32], (12) Pacific bluefin tuna (ocean.si.edu).

Box 1 | Example of valuation of ecosystem services provided across jurisdictions by a marine megafauna species: the whale shark (*Rhincodon typus*)

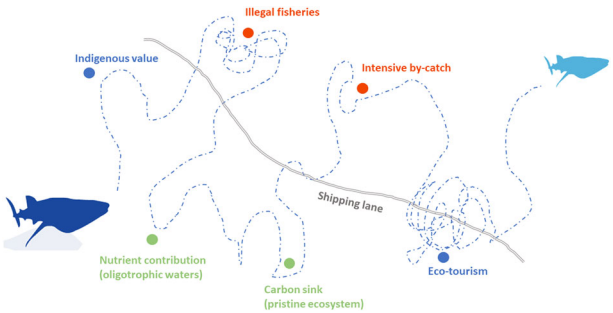
Whale shark (*Rhincodon typus*) is the world's largest fish (up to 18 m total length[35]) with a pan-oceanic distribution[36] likely to be affected by climate change[37]. This species has historically been targeted by fisheries mainly in South-East Asia and India[38–41] and also used as a FAD (fishing aggregating device) in large scale tuna purse-seine fisheries[42]. With the increasingly concerning conservation status of the whale shark (classified as Vulnerable in 2000 and then changed to Endangered in 2016; www.iucnredlist.org), their targeted use in fisheries has been banned[43]. However, **whale shark continued to be one of the most valuable marine species in the meat trade**[44], with a maximum potential value of almost US$ 350 K in traded parts (e.g., shark fins)[45]. Despite regulations on international trade for whale shark products (including meat and fins) by the Convention on International Trade in Endangered Species being in place since 2003, low scrutiny in implementation of bans[46], continued illegal fishing or unintentional catch[41,47,48], and other human-induced threats such as shipping strikes[27] are likely to have assisted the continued decline into a largely depleted global population of whale sharks (as per IUCN red list classification in 2021).

Whale sharks contribute to profitable eco-tourism industry activities in different locations around the world, where they are known to aggregate at specific times of the year, such as in Australia[49], the Seychelles[50], and Mexico[51]. Whale shark eco-tourism is worth around US$66 million worldwide[52]. Davis and Tisdell (1999) found that individual visitors were willing to pay an average of $167 per day (~$308 in 2024USD) for the experience of swimming with whale sharks[53], and in Nosy Be, Seychelles, the value of the tourism operations over the 3-month peak season for whale shark occurrence was US$1.5 million in 2019[54]. Established tourism operations play an important conservation role because of the positive example of economic benefits from renewable tourism. Particularly for whale sharks, the high value of their ecotourism industry[55] has led to a swap of income that replaces previous income obtained through targeted fisheries[56].

Across their geographical ranges, **whale sharks provide an important role in nutrient cycling**: they can dive to considerable depths where they consume prey and then provide nutrient supply through egestion at the surface. The release of nutrients at the surface promotes primary productivity, assisting with carbon sequestration. Additionally, **whale sharks can act as a carbon sink**, similar to whales[8]. Being a large and long-lived species, whale sharks can store a large amount of carbon in their bodies, which sinks to the seafloor when they die to support deep-sea ecosystems[57].

Whale sharks also provide a range of other services associated with their existence. For example, **they are of high cultural value for indigenous communities**, for which sharks are seen as creator beings, ancestors and totems, as is the case for Aboriginal and Torres Strait Islander people[58]. In Australia, carvings of whale sharks may be seen in different locations (https://www.abc.net.au/listen/programs/earshot/indigenous-cultural-views-of-the-shark/6798174), and the burial of a beached whale shark on Indigenous country was considered of cultural value to an Aboriginal community (ABC News 2021-12-17; https://www.abc.net.au/news/2021-12-17/whale-shark-carcass-to-be-buried-on-country/100708428).

The latter values are all complementary to each other, but conflict with the extractive activities associated with fishing, and also suffer from indirect impacts from other activities, such as shipping, which can lead to direct mortality of whale sharks[27]. The figure below depicts the ecosystem services provided by whale sharks as they go about their migrations, including conflicting (orange) and complementary direct (blue) and indirect services (green). The depiction of a shipping lane serves as a reminder that other activities not necessarily associated with whale shark services may also impact or hinder the provision of ecosystem services by whale sharks.



detrimental activities in each location that may impair the provision of the needed ecosystem services, and will be crucial to assist mitigation of impacts on marine megafauna species within a nature-based solution framework. Such framework should focus on measuring ecosystem services "on the move" while assessing how the services and impairments to the services are coupled across locations through which marine megafauna migrate.

The critical role of economic valuation of ecosystem services provided by marine megafauna

The range of services provided by marine megafauna occurs across multiple Exclusive Economic Zones (EEZs) and through the high seas connecting far-apart jurisdictions, where countries with different Gross Domestic Product may have different conservation management and development budgets and interests. For this reason, across the different regions used by marine megafauna, the ecosystem services they provide can be in competition or complement each other. For example, if in one EEZ, marine megafauna are valued for their existence and recreation but in another, they are valued for extractive fisheries, the services they provide across these two EEZs are in competition. If instead of extractive fisheries, the same individual animals are considered a totem species for communities and valued for eco-tourism purposes, then the services provided by marine megafauna complement each other. Where there are competing uses, economic valuation has the important role to identify which uses will generate the largest net benefits and should therefore be considered as a priority.

Table 1 | Illustration of relationships and pathways for transitions needed across Global North and Global South

Uses and Values			Global North (Developed Countries)	Global South (Less-developed Countries)
Conflicting and Unsustainable	Need to prioritise management to transition away from utilising these services		Countries or firms should be incentivised to transition away from current practices. This can happen through regulations requiring penalty or offset payments made to a global fund.	Likely to require financial or other resource support from a global fund to transition local communities from current practices.
Complementing and Sustainable	Need to prioritise management and incentives to maintain or better utilise these services.	Profitable Opportunities	Firms can participate in markets that assist in managing megafauna for these services.	Once established, communities can participate in markets that assist in managing megafauna for these services.
		Non-Market Benefits	Public funds and regulation can manage for these services, and the benefits can be sold as credits.	Governments will likely require financial assistance to support management.

Summary of potential pathways that illustrate the relationship of Global North funds contribution to South transition, leading to a sustainability direction for the Global South. For simplicity, here we represent conflicting values as unsustainable and complementing values as sustainable (despite this not being necessarily true for all values). The complexity of distribution patterns of the marine megafauna and their interactions with human activities cannot be captured in this table, but generally conflicting and unsustainable practices among countries (developed or not) should prioritise transition away from these services with penalties applying (and perhaps gathered in a global fund). Similarly, complementing and sustainable practices should be incentivised and supported, with credits awarded to developed countries, and additional funds provided to less-developed countries. Where activities compete with each other, prevalence of support for complementing and sustainable activities should be provided.

Similarly, where there are complementing (non-extractive) uses that can be aligned with sustainable commercial activities and improved conservation outcomes, economic valuation can demonstrate the additive benefits. Some examples of this type of valuation have been done for sharks, showing that the value of a shark left in the water to be appreciated during tourism operations (including scuba-diving) is financially more beneficial than catching that shark for consumption[1,21]. The identification of value associated with each service provided by marine megafauna can be spatially mapped to isolate competing services and to identify complementing opportunities, such as shifting from extractive fishing practices to ecotourism opportunities as previously demonstrated for sharks. Importantly, economic valuation can be used to identify which communities will benefit (from additive, complementing services) or suffer (from prioritising competing services) from decisions to support conservation management of valued marine megafauna species for specific ecosystem services (see Table 1 and Fig. 2). Quantifying and assessing the value of the benefit resulting from these decisions is key to improving global conservation of marine life in general[22] and marine megafauna, in particular, and assist with the global financing of the GBF.

Migratory marine megafauna as a contributor to GBF financing

Marine megafauna present a yet to be fully appreciated, unique opportunity for modelling how sustainable development at global scale can take place. Given their mobile nature, which connects EEZs across the Global North and Global South and across countries with different levels of development (Fig. 1), highly migratory species, such as marine megafauna, likely present the only nature-based mechanism that connects developed to less developed countries to where financial transfer is needed. The need to protect global biodiversity in support of human well-being is putting a lot of pressure in many less developed countries, particularly where biodiversity is higher, generally due to lower industrial development (among other things). A key focus should be on the fact that uses of marine megafauna include a range of commercially sustainable activities that can support communities' livelihoods while also improving conservation outcomes that are urgently needed across the Earth[23].

The shift to sustainable uses is, however, not straightforward, particularly in the Global South where the financial and social capital may not exist to enable the needed shift. Additionally, shifts may be required in multiple places and communities, for example, to address environmental pressures on migratory species across a chain of sites that may be potential bottlenecks. Infrastructure is needed to help communities transition livelihoods, including governance institutions, as well as the development of facilities, for example, as required for ecotourism operations. Such a cultural shift in the perspectives of the value of marine megafauna, would allow the use of marine megafauna ecosystem services as a vehicle for the generation of funds to support ODA and help the latter transition to complementing uses of marine megafauna towards the global alignment for their conservation management. Defining a value for marine megafauna, and designing the market associated with marine megafauna uses will need to be carefully thought out to ensure that the impact of credit purchases or attribution of penalties is specific to activities that can be traced back to countries, and not a result of other impacts, such as ecological system changes. For the latter, distinction between human-induced changes, such as those from climate change, and natural changes will also need to be well defined. And more broadly, the feedback this suite of changes could collectively have on the socio-ecological system will also need to be understood.

Market-based schemes are already in existence and offer examples of frameworks that can be used to enable the proposed financing from the

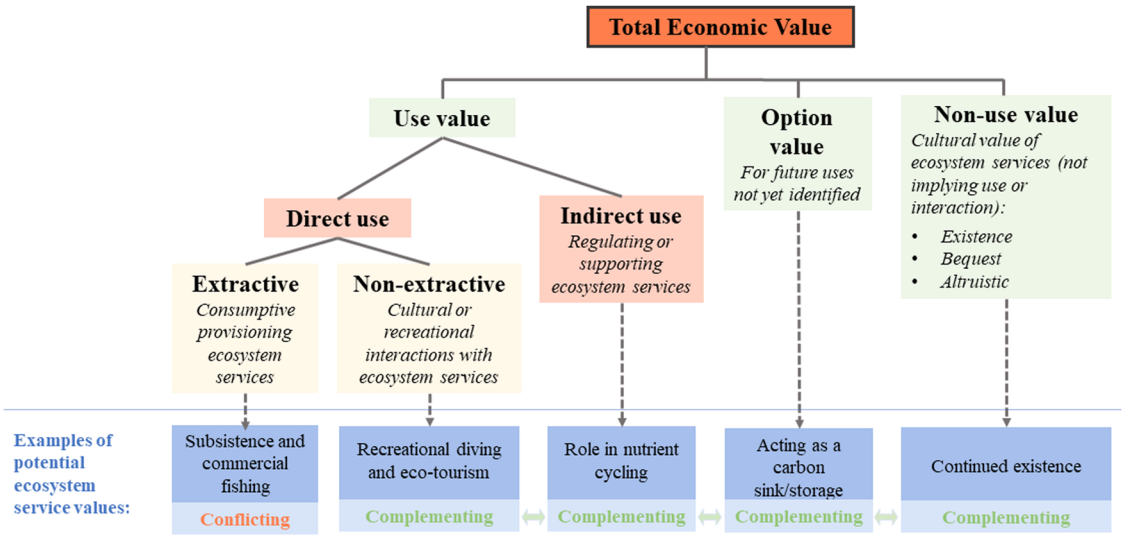


Fig. 2 | Using the Total Economic Value framework to prioritise the ecosystem services of migratory megafauna. Example of how the TEV framework can assist in identifying where conflicting and complementing values exist, across different value categories, to isolate which ecosystem services provided by marine megafauna should be prioritised and align value generation with conservation. We note that our focus is on proposing the financing mechanism and on how to identify cases that can fund versus cases that could be funded. With this objective, we propose to use economic valuation to identify the most highly valued 'uses' of marine megafauna (including non-use related values of conservation), not the value associated with a full transition to a new sustainable management programme that might support conservation of marine megafauna (as we do not discuss full implementation of the mechanism here).

Global North to the Global South. The carbon market is a good example of international trading between entities for purchase of a carbon credit[24]. Similarly, biodiversity credits[25] and nature repair markets[26] are currently emerging using analogous principles. As part of the value attributed to marine megafauna species, specific credits or penalties could be placed in activities from the Global North that directly affect or impact marine megafauna. Penalties could be applied to activities where there is a lack of action to alleviate known threats, specifically those leading to mortality, such as, shipping leading to strikes[27] and commercial fishing by Global North-flagged ships leading to bycatch[28]. Credits could be generated for measures that alleviate the threats posed by activities taken by different countries. For example, changes in shipping lanes to avoid ecologically important areas for marine megafauna in the high seas or to undertake known mitigation measures in fisheries[29], could revert into credits that can be sold both to fund the industry changes and contribute profits to a global fund. While credits for purchase may initially be provided through projects led by Global North industries, over time, and with support to transition towards the required infrastructure, Global South communities could be equipped to implement such measures that they can also contribute to the market as credits for purchase, creating a self-sustaining finance mechanism to continue such measures. Global commitments to deliver on related initiatives, including through governments electing to include ecosystem services in their national reporting using the UN System of Environmental Economic Accounting (seea.un.org/ecosystem-accounting) and organisations advancing the Nature Positive Initiative (naturepositive.org/about/the-initiative/), will have similar research and infrastructure requirements, such that the foundations to enable this financing mechanism can be supported through complementing programmes. Assessment of credits or penalties should be grounded in scientifically based evidence for what constitutes a benefit or a threat to marine megafauna biodiversity globally. The value of credits will need to be assigned using certified methods of best practice for valuation, to ensure consistency in approach (e.g., as done in the carbon credit system used in Australia; https://www.dcceew.gov.au/climate-change/emissions-reduction/emissions-reduction-fund/methods). The resulting payments could then be transferred to Global South organisations responsible for implementing the shift needed in support of a change from conflicting (e.g., extractive) to complementing (sustainable) activities. Funds would, therefore, be used to help deliver the infrastructure needed for the alternative livelihoods, and to ensure compliance in terms of species protection from extractive or other unsustainable uses. In summary, a well-defined environmental market system would allow estimation of costs and benefits of activities and the impacts they have on marine megafauna and can be used to assess the level of payment or compensation to be provided between countries to assist implementation of the GBF. Although such market system would not be sufficient to estimate the value associated with a transition to a new sustainable management programme in support of marine megafauna conservation, using the TEV framework would be a first step in identifying the value associated with the ecosystem services they provide. Within this context, it is appropriate to arrive at a conclusion that the existence value of a marine megafauna species in a particular location is more highly valued than the consumptive value of the same species elsewhere, allowing the first conclusion that conservation of this species should be prioritised. An immediate next step could then be to identify the lower value, conflicting cases, where funding can be used to implement a transition to a new sustainable enterprise. This would serve as the basis for a financing mechanism after identification of cases that should provide funding versus cases that should be funded. The implementation of the funding strategy will need to be fully developed, and requires its own evaluation, for example through a benefit-cost analysis of the multiple values associated with stopping or starting different activities or alternative practices, including the potential loss versus creation of jobs or industry profits versus damage, and any aspects associated with gender equity or education opportunities.

In this work, we highlight that leveraging the services provided by marine megafauna as they travel across jurisdictions could significantly aid conservation efforts, help achieve the GBF financing goals, and support the sustainability of both marine ecosystems and human communities. Outlining the economic potential of marine megafauna's mobile behaviour provides the first nature-based mechanism to economically connect far-apart countries between the Global North and Global South providing a basis to ground global financing for much-needed biodiversity conservation. Converting marine megafauna services into economic value will be challenging due to disparities between developed and less developed nations, governance differences, as well as the complexity of measuring values across diverse contexts and cultures. However, other emerging markets associated with nature restoration and biodiversity credits will provide some clues for how to proceed. Our proposed approach

underscores the significance of charismatic marine megafauna, our global heritage, and could offer insights into solving other financing challenges for achieving GBF targets.

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Author contributions

A.M.M.S. conceived the study. A.A.R. and U.R.S. assisted with developing ideas. A.M.M.S. led the writing of the manuscript, with significantly contributions from A.A.R. and U.R.S. A.M.M.S. and A.A.R. prepared tables and figures.

Competing interests

The authors declare no competing interests.

Additional information

Correspondence and requests for materials should be addressed to Ana M. M. Sequeira.