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Managing tourism in Antarctica: impacts, forecasts, and suitable economic instruments

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ABSTRACT

Rapid growth in tourism to Antarctica has led the Antarctic Treaty Consultative Parties to launch a multi-year process to develop a framework for managing Antarctic tourism. Managing tourism in this region poses particular challenges, given the remoteness, ecological sensitivity and complex institutional systems. Approximately 65% of the current 120,000+ Antarctic cruise tourists travel on 'expedition' vessels that allow landfall. Landings are concentrated in relatively few locations, with potential for localised impacts. All vessels, including larger 'cruise-only' vessels that do not land passengers, generate carbon emissions, thus indirectly impacting the region. Using historical data, we forecast that tourist numbers could quadruple from current levels in ten years, with the largest growth occurring within the 'landed' sector. With these forecasts in mind, we consider a variety of price-based, quantity-based, and 'market-friction' economic instruments and assess their potential *effectiveness* (curtailing impacts or slowing growth in landings) and their potential *acceptability/suitability (*within existing governance systems) in this unique place. Our analysis suggests that it may be possible to forestall impacts by complementing existing regulations and guidelines with a combination of quantity-based instruments, nudging, and tighter certification. There are, nonetheless, practical difficulties, including the contrasting interests, values and political priorities of the twenty-nine Consultative Parties.

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Introduction

Antarctica and the adjacent Southern Ocean (A&SO) are remote and relatively pristine areas of the planet. The region provides a range of important ecosystem services (Cavanagh et al., 2021;

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Deininger et al., 2016; Pertierra et al., 2021) that have been conservatively estimated to contribute ~ USD$180 billion annually to the welfare of global populations (Stoeckl et al., 2024). However, the growth of the tourism market in the region has raised alarm in the media and the academic literature (Clemence, 2023), with visitor numbers rising rapidly from just under 8,000 in 1993–1994 to over 120,000 in 2023–2024 (International Association of Antarctica Tour Operators, 2024). A core concern is that the cumulative impacts of tourism (such as soil compaction, pollution, and the increased risk of establishment and spread of invasive species and wildlife diseases such as avian flu (Wong, 2024) will interact with climate-change-induced shifts in weather patterns, ice melt, ocean currents and nutrient cycling, resulting in widespread habitat degradation and declines in wildlife populations and diversity (Huddart et al., 2020; Pirotta et al., 2015). Put more bluntly, Antarctica may be in danger of joining other globally iconic destinations which have been reportedly *loved to death* (Morella, 2018; Nainar, 2018).

Worldwide, limiting tourism impacts has sometimes proven challenging, with self-regulation or limited enforcement of official regulation resulting in a cascade of environmental and social impacts (Brenner et al., 2018; Burbano and Meredith, 2021), especially in locations where tourism expanded rapidly. Tourism in the Galapagos Islands experienced a rapid expansion since the early 1990s at an annual rate of 9%. While this growth has boosted the Islands' economy and generated support for conservation projects, overtourism has generated negative impacts including overpopulation, increased socioeconomic stratification, congestion/excess demand for scarce infrastructure, increases in invasive species, and growing conflict between conservation objectives and visitor satisfaction (Benitez-Capistros et al., 2014; Mathis and Rose, 2016). The constant pressures that tourism has imposed on the fragile, insular ecosystems prompted the Ecuadorian government to introduce boat permits to transport passengers, entrance fees, and zoning to limit vessel numbers (Epler, 2007). The net impact has been to increase local revenue and marginally slow the growth in visitor numbers. The Galapagos Islands case provides salient warning for Antarctica: intensive tourism development raises the risk of invasive species and other negative impacts if not managed carefully (Mathis and Rose, 2016).

Concerns about the potential negative environmental impacts of tourism in Antarctica have been widely discussed for at least three decades (Hall, 1992). The observed growth in tourist numbers, the diversity of activities undertaken, and the diversity of sites visited all increase the chance that this industry could negatively impact the Antarctic region. In response to these rising concerns, in 2023 the twenty-nine states with decision-making power in the Antarctic region—the Antarctic Treaty Consultative Parties (ATCPs)—agreed to work towards a "comprehensive and consistent framework for Antarctic tourism and other non-governmental activities" (ATCM, 2023).

Our paper aims to contribute to this process by outlining and evaluating a range of economic instruments that could potentially augment regulatory and legal frameworks. Our primary goal is to identify practical ways to manage for the potential impacts of this rapidly growing and diversifying Antarctic tourism industry *before* reaching a tipping point of irreparable change (Butler and Dodds, 2022). This is a non-trivial challenge, given the remoteness of the region and the complex institutional arrangements (outlined below) in which the industry operates (Cajiao et al., 2021). We take an interdisciplinary approach, which we argue is necessary to face the challenges of a rapidly expanding industry in a period of human-induced environmental change that is already having significant impact in this and connected regions (Auger et al., 2021; Convey and Peck, 2019; Constable, 2023; Siegert et al., 2023).

Globally an array of policy/management instruments have been used to control or mitigate the (potential) impacts of tourism (Atkins and Macpherson, 2019; Haase et al., 2009; Ostrom, 2008), with varying degrees of success. When a robust governance structure is not in place and a comprehensive plan for integrated management of human activities is lacking, options for managing tourism may be limited to site-specific codes of conduct and guidelines. The effectiveness of such guidelines relies on the commitment of the tourism industry to adherence.

The validity of such regulations can be challenged if the measures are not deemed to be worthwhile or legitimate across institutions and users (Llausàs et al., 2019). In the Antarctic context, the use of economic instruments alongside and in support of existing arrangements is likely to be necessary. If well-designed and administered, these instruments can alter behaviours without stifling the potential to innovate technologies to mitigate environmental impacts (Kalkuhl et al., 2012). Different instruments are suited to addressing different problems, so it is important to select carefully. It is likewise important to recognise that economic instruments are not a substitute for regulation, treaties, or agreements but in fact rely on a working set of legal and institutional arrangements.

Effective management of Antarctic tourism requires understanding both the destination and the institutional setting, a context we briefly describe in section two of this paper. In Methods, we present our approach to mapping historical visitation data, forecasting tourism numbers and evaluating the existing suite of economic instruments available that could be used in this setting. In Results, we present a map of where most visitors land and identify tourism hotspots and forecasts of projected visitor numbers based on historical trends. Having established the need for new tools to manage tourism numbers, particularly in hotspots, we identify and discuss in section four a variety of price-based, quantity-based, and 'market-friction' economic instruments that have been successfully implemented in other tourism settings and assess their potential *effectiveness* (curtailing impacts or slowing growth in ecologically sensitive areas) and their potential *acceptability/suitability (*within existing governance systems). In section five, we synthesise insights from our assessment of instruments and identify a mix of tools most suited to the unique geographic, ecological and institutional features of the region.

Background

Tourism and tourism impacts in the Antarctic region

Antarctic tourism arguably began in the late nineteenth century, depending on definition of tourism and the Antarctic region. Regular expeditions, however, began in the late 1960s. From the early 1990s, with the availability of ex-Soviet icebreakers, the industry began to burgeon. Shipborne tourism predominates, with 98% of voyages visiting the Antarctic Peninsula and departing from ports in South America, primarily Ushuaia in Argentina. They travel only in the summer and shoulder months (October-April) (Cajiao et al., 2022; Picard and Zuev, 2014; Stoeckl et al., 2025; Vila et al., 2016).

In 2023/24, over 120,000 cruise tourists travelled to the region, with about 65% travelling on vessels that enable landfall and participating in a diverse range of activities (International Association of Antarctic Tourism Operators, 2023a, 2023b). The number of tourists undertaking deep-field experiences, such as skiing, mountaineering, and skydiving, has more than doubled in the last decade, reaching just under 800 visitors in the 2023–24 summer season, with over 1000 predicted for 2024–25 (International Association of Antarctic Tourism Operator, 2023b). Potential impacts from tourists landing on the continent include: soil compaction, vegetation disruption, introduction of non-native soils/microbes/plants, disturbance of bird or seal breeding colonies (Erbe et al., 2019; Leaper and Miller, 2011), non-scientific collecting (Luck et al., 2010), damage to heritage sites, the risk of introducing invasive species or wildlife diseases (from shoes and clothing or ship discharges) (Wong, 2024), landscape disturbance, and pollution (Liggett et al., 2023; Tejedo et al., 2022). A relatively large number of visitors are cruise-only, with potential environmental impacts from seaborne tourism that include: waste disposal/fuel leaks (Amelung and Lamers, 2007), anchoring, air pollution (e.g. black carbon), anti-fouling agents from ship hulls (Woehler et al., 2014), noise (Tin et al., 2014), and congestion.

Like other motorised forms of travel, vessels traveling to the Antarctic produce a series of carbon and carbon equivalent emissions. In 2011, the average, single Antarctic tourist voyage

(including travel to the departure port) was estimated to entail more carbon than the average person in the world for the whole year (Farreny et al., 2011). Some operators apply carbon offsets and others have introduced hybrid ships. Emissions per capita also depend on other factors, such as occupancy rates (Li et al., 2022). Recently, operators belonging to the International Association of Antarctica Tour Operators (IAATO) pledged to reduce emissions (compared with 2008) by 50% by 2050. This goal is still short of the pledge of many countries and the International Maritime Organization to reach Carbon Net Zero emission by 2050 (and some by 2040, e.g. British Antarctic Survey). Such goals may not be realistic for vessels without significant advances in technologies, ship redesign and fuel substitutions towards technologies such as hydrogen (Ramírez, 2022). Despite IAATO's goal, the cumulative carbon emission of ship-borne tourism in Antarctica is increasing, with emissions per passenger-trip estimated between 3.2t and 4.1t (Li et al., 2022). Ultimately the challenging conditions, distances involved and lack of infrastructure in the Antarctic region may place limits on decarbonisation in terms of fuels used in vessels.

Antarctic tourism may also create opportunities for positive outcomes. For example, operators frequently provide logistical support for scientists or undertake data collection that feeds into scientific research. Citizen science is a popular activity, with the potential for providing useful data and giving tourists a greater awareness of scientific activity and a sense of investment in Antarctica's protection. Antarctic tourism can thus increase environmental awareness and support for researchers (Liggett et al., 2023), although there is scant data with which to assess tangible impacts from these activities (Eijgelaar et al., 2010). The concept of "Antarctic ambassadorship"—the idea that an Antarctic voyage can transform tourists into advocates for the continent (Alexander et al., 2019)—is strongly and explicitly promoted by IAATO (International Association of Antarctic Tourism Operators, 2025), although existing research suggests the effect is at best short-term (Cajiao et al., 2022). Studies of what factors might increase or inhibit this effect, and how it manifests over the long term, are similarly lacking. We note also that Antarctic tourism can have both negative and positive effects on the 'gateway' ports which operators use as a base (Herbert et al., 2020)—however, we are primarily interested in impacts on the Antarctic continent, so do not discuss those broader impacts further.

Current tourism governance

For over sixty years, human activity in Antarctica has been governed by the Antarctic Treaty System (ATS), an evolving collection of legal instruments with the 1959 Antarctic Treaty at its heart. A core part of the ATS is the 1991 Protocol on Environmental Protection to the Antarctic Treaty (Madrid Protocol), which applies to all human activities in Antarctica, explicitly including tourism. The Protocol requires an environmental impact assessment (Guix et al., 2022) to be conducted prior to initiating any activity in Antarctica—although results and recommendations from these assessments are not subject to further international decision-making (Bastmeijer et al., 2023).

Further environmental protections have also been established through IAATO, to which all commercial passenger vessels covered under to the International Convention for the Safety of Life at Sea (SOLAS) belong (International Association of Antarctic Tourism Operators, 2023a). IAATO's mission is "to advocate and promote the practice of safe and environmentally friendly private-sector travel to the Antarctic (International Association of Antarctic Tourism Operators, 2025)." IAATO has a series of bylaws (some of which have been adopted by the ATCPs), tools and practices that seek to minimise environmental harms and maximise wilderness experience. These include restricting the size of ships that can land passengers; imposing biosecurity measures and guide-training requirements; coordinating ship movements to prevent congestion and overuse; and providing guidelines for commonly visited sites. As an industry association, IAATO cannot itself limit travel, but rather aims to promote safe and sustainable options.

The issue of tourism was first raised in a regulatory context in 1966 at the fourth Antarctic Treaty Consultative Meeting (ATCM IV). Since 1968, a range of tourism management options have been discussed within ATCMs (Bastmeijer et al., 2023), with a recent literature review by Cajiao et al. (2021) reporting over 169 different recommendations relevant to Antarctic tourism discussed across 72 articles published in the scientific literature. Some economic instruments (including a tourism tax, caps on tourism numbers and the development of an accreditation scheme) have been mentioned, but not fully explored, as options to manage impacts (Bastmeijer et al., 2023). The consensus-based approach to decision-making inherent to the ATS, combined with states' differing views on Antarctic tourism, means that progress is slow. Thus far, no binding measures to regulate tourism have occurred since 1998, when the Environmental Protocol did so. The current system thus largely relies on the industry to self-regulate.

In recognition of this problematic situation, the ATCPs recently committed to developing a systematic framework for regulating tourism and other non-governmental activities. A 2024 ATCM Decision identified a number of focal topics, including managing growth and diversification, and explicitly identified one economic instrument (fees) as a possible point of discussion (ATCM, 2024). As yet, however, there has been no public debate on the advantages and disadvantages of including different economic instruments in this framework. Section four provides a basis for such a debate.

Methods

We use historical visitation data to develop a map that shows where most visitors land and generate forecasting models that allow us to project visitor numbers into the future. We then consider a variety of price-based, quantity-based, and 'market-friction' instruments that have been successfully implemented in other tourism settings. We identify specific issues that need to be addressed prior to use in an Antarctic setting.

Mapping tourist visitation

Quantifying tourism impacts in Antarctica and developing robust impact indices is challenging, as data are scarce for some areas and numerous changes are impacting the region. Further, we do not know if combined impacts are additive, synergistic, or antagonistic (Gillingham, 2016; Pirotta et al., 2019). Adaptive behaviours in both the natural and human environment add further complexity to the assessment problem, making it infeasible to rapidly assess the cumulative impact of multiple stressors (Murray et al., 2021; Willsteed et al., 2023). While global cumulative mapping exists and is a useful management tool, it is necessarily focused on all human uses and thus has limited inferences specific to tourism management (Halpern, 2008).

Lacking sufficient data to accurately map impact, we used two decades of industry data (International Association of Antarctic Tourism Operator, 2023b) to visualise tourism hotspots, highlighting which regions are most visited and/or have a wide range of activities offered to tourism and thus, potentially, a greater impact. IAATO provided digitalized data files based on post-visit reports. Per visited site on Antarctica, data about the number of activities is provided for 47 different activity types (e.g. small boat landing, polar plunge, kayaking). ArcGIS and PowerBI were used to visualize the data.

We also included the current and proposed Antarctic Special Protection Areas and Antarctic Special Management Areas (established by the ATCPs through the Protocol on Environmental Protection to the Antarctic Treaty) and Marine Protected Areas (established by the Commission on the Conservation of Antarctic Marine Living Resources) as a way of identifying sites that are considered either already impacted, at risk, or particularly sensitive and thus in need of

protection. Geographical coordinates for these areas are provided publicly by the Australian Antarctic Program and downloadable from https://data.aad.gov.au/metadata/aspas_asmas_aat.

Forecast of tourism growth

We used 30 years of historical data on visitors in Antarctica. The visitor data up to the 2022–2023 season were downloaded from https://iaato.org/information-resources/data-statistics/visitor-statistics/visitor-statistics-downloads/ on 8th January 2024, but the data are no longer available at that site. Interested persons are now asked to email the secretariat if wanting to access the data. The visitor data for the recent 2023–2024 season were retrieved from the IAATO report (International Association of Antarctica Tour Operators, 2024). This data was used to forecast the annual visitors' tally over the next ten years. Due to the limited information available and the lack of data on influencing factors (i.e. tourists' income, demographics, etc.), we applied a non-causal time series modelling framework to generate forecasts (Song and Li, 2008). This analysis represents a potential scenario if no additional tourism management actions are undertaken.

Preliminary data exploration revealed an exponential trend in the raw data describing total visits V at time t (V_t), so we linearized the visitation data prior to modelling by taking the natural logarithm values multiplied by 100. We then estimate integrated autoregressive moving average models (ARIMA) and used the Bayesian Information Criteria (Kreibich and Hermwille, 2021) to select the best fitted models, which we employed to generate forecasts. We then used that model to generate forecasts for different groups of visitors:

1. All visitors
2. Visitors travelling on ships with > 500 passengers (not permitted to land)
3. Visitors travelling on ships with ≤ 500 passengers (who are permitted to land).

For each group of visitors, we also used different subsets of data to allow for the effect of the lockdown during the COVID-19 pandemic. Further details are provided in Supplementary Appendix A.

Categorising economic instruments

Through desk research we identified a wide range of economic instruments that are available to manage tourism. We categorized them primarily as price-based or quantity-based, but also included an additional category of instruments that are designed to reduce market-frictions (Weitzman, 1974)—see Figure 1.

Price-based instruments are numerous and diversely named. Some change prices in existing markets (through taxes or subsidies) and some 'create' prices and markets which did not previously exist (e.g. creating carbon markets, biodiversity offsets, payments for ecosystem services). Price-based instruments essentially tax (increase the price of) undesirable behaviours and reward (subsidise) desirable behaviours. These instruments have been successfully employed for conserving migratory species in the face of coordination and jurisdictional challenges similar to those of Antarctic tourism (López-Hoffman et al., 2017). Price-based instruments can be applied temporally (per season or part thereof); spatially (at sea or on land); or according to the activities of the tour operators (e.g. anchoring, landing, helicopters, etc.). In general, the goal for taxes is to set the rate that effectively ensures people 'pay' for the incremental damage done (or that they are 'rewarded' for incremental benefits). The intention is to make visible otherwise invisible costs (or benefits), so that people take these factors into consideration when making decisions.

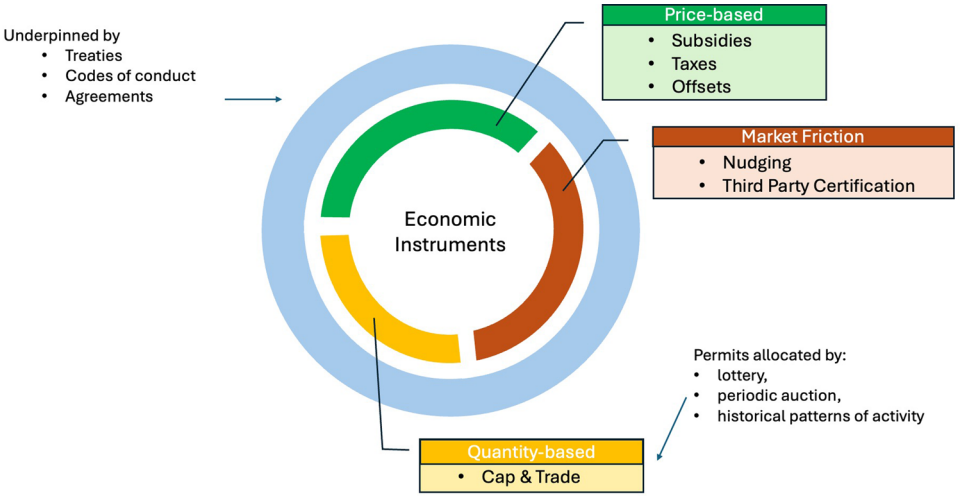

Figure 1. Types of economic instruments available and how they should be implemented within the governance of treaties, codes of conduct and agreements.

Offsets are often categorized as a price-based instrument (with an offset bank or offset providers categorised as reducing market-frictions). In this context, tourism operators would make a series of payments to an offset bank to fund projects, in other locations, to compensate for damages caused by their activities. The aim is to avoid damage where possible, and then to identify unavoidable damages and find another location or situation to offset (using a 'like for like' principle). Offsets can be used to manage impacts that are indirect (e.g. climate change) or direct (e.g. marine pollution).

Quantity-based instruments work by first setting an overall cap on quantity—e.g. the total number of tourists allowed to land at a particular site—and then providing some flexibility about the way in which the allowances/permits are distributed and managed (e.g. on the number of tourists and/or operators). Allocating overall tourist/ship permits and/or allocating overall market permits can be facilitated once an appropriate binding cap on the number of tourists is agreed upon with the aim of minimizing the human footprint. Although not used as frequently as taxes and subsidies, quotas/caps and permits have been trialled in locations such as Bhutan (World Economic Forum, 2023) and various lower-latitude tourist settings such as Lord Howe Island (Allman, 2021).

Market-friction tools comprise a varied set of instruments which improve flows of information, reduce transaction costs, or make it 'easier' for people to undertake desired environmental behaviours. Certification schemes and product labels help to improve market performance by providing better information—the overall aim being to make it easy for customers to identify, and select, ethical operators. They have long been used in tourism; one of the first, *Blue Flag,* started in France in 1985 and there are now more than 200 distinct ecolabels in the tourism industry (Bučar et al., 2019). Simplistically, tourism operators apply for certification, and are independently assessed on their ability to meet certain standards and when these standards have been met, operators are provided with a certification logo (Font, 2002). This is intended to help tourists identify 'responsible' operators, so they can make ethical choices (Chamorro and Bañegil, 2006; WTO, 2005); the logo thus helps tourism operators with branding.

Nudging is another type of market-friction tool—one that explicitly leverages the knowledge that people do not always behave 'rationally', even when they have all required information. Nudging aims to steer people's behaviour in a desired direction (Thaler and Sunstein, 2009). In some cases, the nudge works by making the desired behaviours the status quo or at least an easy option while preserving the right of the individual to make choices. Examples of nudges

in the tourism industry include reuse of towels (Goldstein et al., 2008), water conservation and more sustainable eating options (Souza-Neto et al., 2022).

In the Antarctic context, some or all of these economic instruments could be used alongside and in support of existing arrangements, providing the parties with an expanded set of options. If well-designed and administered, these instruments can alter behaviours without stifling the potential to innovate in mitigating environmental impacts (Kalkuhl et al., 2012). Different instruments are, however, suited to redressing different problems, so it is important to select carefully. It is likewise important to recognise that economic instruments are not a substitute for regulation, treaties, or agreements but in fact rely on a working set of legal and institutional arrangements. These tools should be used in conjunction with effective monitoring and enforcement as well as a comprehensive management plan (Agrawal, 2003). In 'Assessment of economic instruments for Antarctica' section, we consider those issues, outlining how each instrument would need to work, and identifying implementation issues, if used in the Antarctic. Supplementary Appendix B presents definitions of economic instruments from a broader international context.

Results

Tourist visitation

Currently, tourism in Antarctica is mainly concentrated around the Antarctic Peninsula with a small percentage in the Ross Sea region and parts of the continent's interior. Many of the most sought-after tourism sites (with potentially high tourism impact) lie near established or proposed protected areas, including Marine Protected Areas, Antarctic Specially Protected Areas and Antarctic Specially Managed Areas (Figure 2). While tourism and other activities may be allowed under certain conditions, the designation of these areas as protected highlights their importance and suggests the need for in-depth impact assessment, especially in light of increasing utilisation and diversification of activity types. Figure 2 provides a map of activities to point locations for the 2022/2023 season (and is thus best interpreted as spatially coarse filter mapping). This map could be further refined to take into account the type of ecosystems and species present at each site and their sensitivity to different activities as cumulative impacts (Ostwald et al., 2021). The latter is particularly important as various activities can have a multitude of effects, and these can be species- or location-specific. Figures 3 and 4 represent the temporal evolution and diversification of touristic activities within a decade, from 2003/2004 to 2022/2023.

Forecast of tourism growth

The selected model is a random walk process that shows if visitor numbers grow at the average annual growth rate from the 1992–1993 season to the 2023–24 season (a constant annual growth rate of 14.0%), total visitor numbers are expected to nearly quadruple in 10 years (Figure 5), tallying to approximately 452,000 by the 2033–2034 season (see Supplementary Appendix A for more detail).

Assessment of economic instruments for Antarctica

The instruments identified in Figure 1 ('Categorising economic instruments' section) help redress or mitigate third-party impacts or costs imposed outside the market transaction, whether these 'externalities' are imposed on others or the environment. Economic instruments are not a substitute for existing Antarctic policy and planning processes of the parties. Instead, an instrument should augment and work within the existing regulatory frameworks providing additional positive or negative incentives to change production and consumption behaviour (Morin and Richard, 2021).

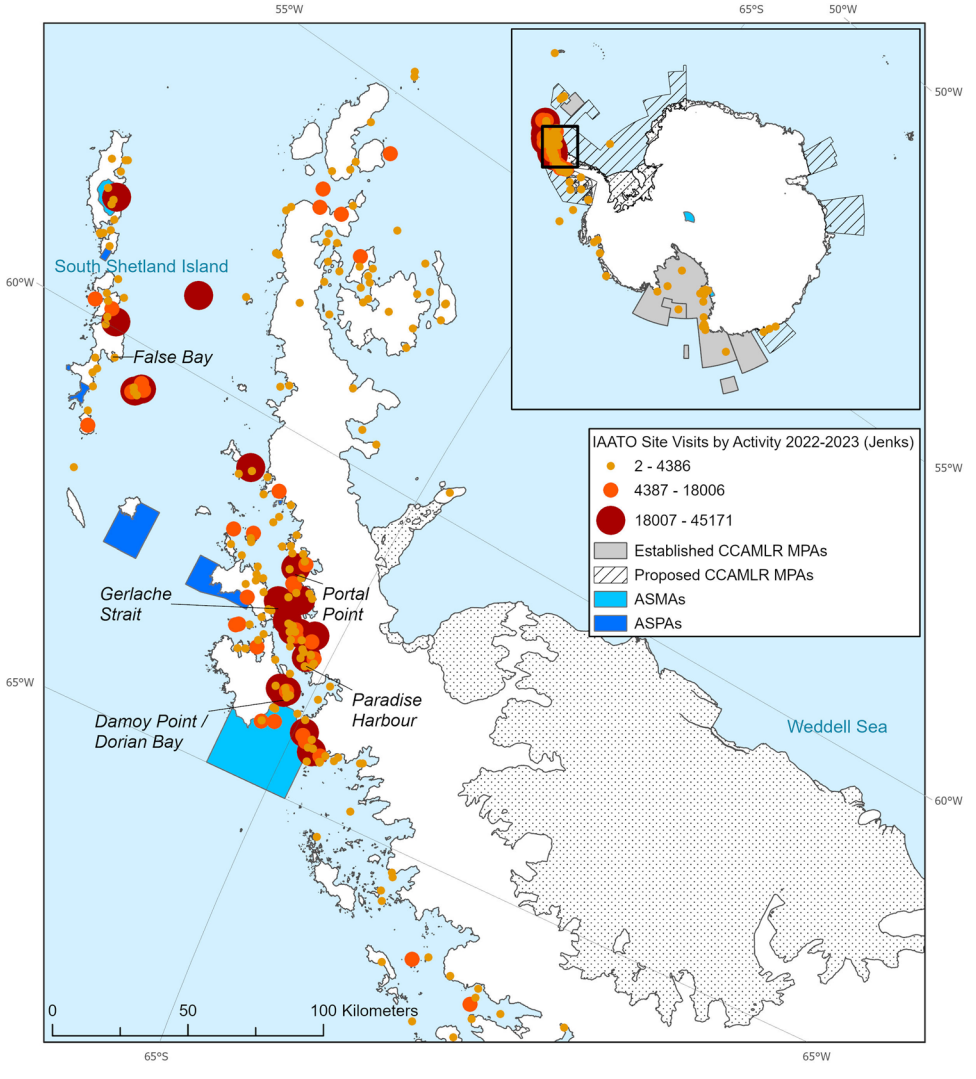

Figure 2. Tourism site impacts in Antarctica. Size and colour of bubbles show estimated relative number of land-based activities occurring across the continent and more specifically along the Antarctic Peninsula.

Price-based instruments

Changing prices (e.g. using taxes or subsidies). In the Antarctic context, a tourism tax would need to be designed to cover costs associated with negative impacts (e.g. soil compaction, congestion associated with ships, acoustic pollution and impacts on wildlife). These costs would presumably be highest for activities that generate the most negative impacts (e.g. helicopter trips, compared to travel on hybrid ships). Also, subsidies could be designed to encourage positive impacts (e.g. investment in green energy). Critically, taxes/subsidies can punish/reward certain behaviours, but one cannot be certain that behaviours will change (not all cigarette smokers quit when prices increase).

Responding to an ATCM Information Paper submitted by the Netherlands in 2012 which mooted the idea of tourists or tourist organizations making "voluntary or obligatory payments" (Bastmeijer, 2012), Verbitsky (2018, 2015) has examined the challenges and opportunities of an Antarctic tourism tax. We concur with Verbitsky that a tax scheme would be beneficial to

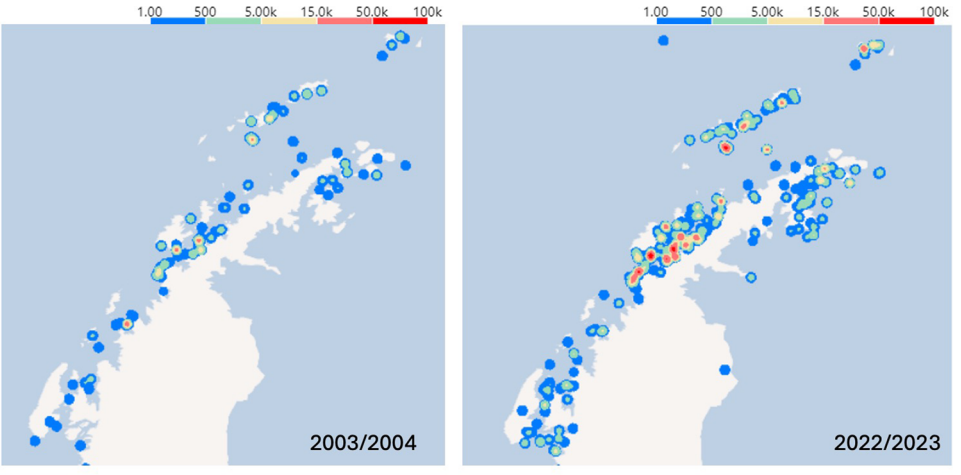

Figure 3. The figures visualise the diversification of tourism after two decades of tourism development in Antarctica, based on numbers of activity types per location comparing across 20 years.

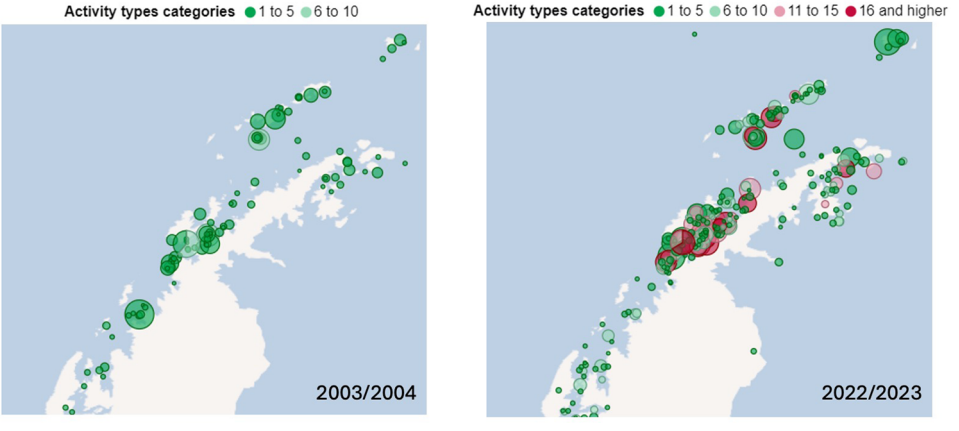

Figure 4. The figures represent the growth of touristic hotspots as the sum of all activities taking place at each location–regardless of activity types. Note that a single tourist can participate in multiple activities.

manage tourism in Antarctica and that it should be made clear that the establishment of an ATS institution to administer such a tax will not pose a threat to sovereignty claims. Implementing a tourism tax might additionally be facilitated by the cooperation of parties such as the IAATO, International Maritime Organization, and International Civil Aviation organization.

However, even with in-principle cooperation, imposing taxes at a level sufficient to induce large changes in behaviour could be challenging. Antarctic tourism is characterised by different market segments, with some more likely to be more responsive to price signals than others. Some emerging Antarctic tourism segments, such as the more budget-orientated market, could be responsive to price signals and substitute other destinations. With more price responsive segments, if the tax is set too low, tourist numbers will continue to increase, perhaps at a slower rate. If the tax is set too high, tourist numbers may plummet in the short term, with the potential for rogue operators basing themselves in states that are not signatories to the Environmental Protocol. Key is setting the tax at the right level to attain a sustainable level of tourism. This may require setting and readjusting the level of the tax, noting that this creates

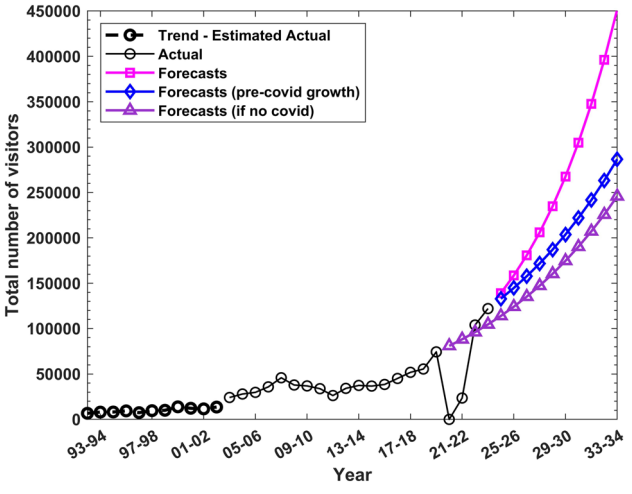

Figure 5. The observations and forecasts of the total number of visitors to Antarctica: from 1992–1993 to 2033–2034.
Note: Pink lines represent forecasts using all past observed data, including the significant growth in the 2022–2023 seasons due to the recovery from the COVID period. The blue line represents forecasts using the average annual growth rate during all the pre-COVID seasons, which was 8.9%. The purple line represents forecasts made in a hypothetical scenario where COVID-19 never occurred. These forecasts are computed for the seasons starting from 2020–2021 using an estimate annual growth rate of 8.9%.

uncertainty for tourist operators about how many tourists will arrive each year, especially if the types of tourists are changing.

Unique experience tourism is thought to be largely unresponsive to changes in price, as is nature-based tourism (Farr et al., 2011; Knapman and Stoeckl, 1995; Lindberg and Aylward, 1999; Miller et al., 2018). In this sense, tourism taxes may be an effective way to raise revenue but may not be effective in reducing visitor numbers to Antarctica. If taxes are unable to reduce visitation and/or if subsidies are unable to encourage visitors to make more sustainable tourism choices, then the question of whether or not tourist taxes/subsidies are able to 'deliver' on the promise of improved sustainability will depend on the way in which revenues are invested (McCartney, 2020).

'Creating' prices and markets (e.g. environmental offsets for purchase). It is straightforward to meet the 'like-for-like' principle with the indirect impacts of carbon as this can be sequestered to achieve zero net gain globally. Carbon [offset] markets are well established, and the industry and travellers to Antarctica frequently purchase carbon credits to offset the impacts of their travel (Denton et al., 2020; Guix et al., 2022). However, the voluntary carbon market is controversial, as the major certification schemes have failed to supply carbon credits of sufficient quality that satisfy the architecture of the Paris agreement (Kreibich and Hermwille, 2021).

Biodiversity [offset] markets are becoming more common, although they are arguably more challenging to effectively implement than carbon markets and face widespread critique (Devictor, 2015; Griffiths et al., 2019; Peterson et al., 2018; Tarabon et al., 2021). The UN recommends that direct (localised) impacts need to be mitigated within the region of impact, but the uniqueness of Antarctica would make it exceedingly difficult (perhaps impossible) to meet the like-for-like principle in this regard. Where else on the planet, for example, could one undertake compensatory restorative works to offset harm to Adélie penguin nesting sites? Some biodiversity researchers have claimed that the strict like-for-like principle could be relaxed (Bull et al., 2015), but this is controversial (Zu Ermgassen et al., 2020). An alternative way of approaching offsets might be for the Consultative Parties to agree that any expansion of landing sites (or visitor numbers) would be contingent on meeting all existing obligations as well as investing in

additional projects which address past environmental harm in the region or pressing environmental problems. The approach allows for some new development while improving biodiversity outcomes—although there would be jurisdictional challenges to navigate.

Quantity-based instruments

If used in Antarctica, visitor caps would ideally be established based on proper assessment of the environmental resilience with respect to cumulative impact from anthropogenic activities and natural stochasticity. In Antarctica, a precise estimate of environmental resilience is not available. Figure 2 can be used as a prioritisation tool for further research and cap estimation, but research should explore spatial vulnerability indices, ensuring a cap on tourism numbers that minimises disturbance and ensures the long-term sustainability of the industry.

Once a suitable spatial cap on tourists and permitted tourist activities has been established, the challenge then lies in developing a way to allocate permits. Several means of allocating permits can be envisioned for Antarctica. If signatories to the Protocol on Environmental Protection to the Antarctic Treaty were awarded a share of the tourist cap, these states could then independently determine how best to distribute permits under their Environmental Impact Assessment system. The risk of this approach is that it excludes non-signatories from a cap-and-trade system, which could attract criticism of a closed club. It could also provide an incentive to operate outside of the ATS, using ship flags and basing companies in nations that are not signatories to relevant instruments. The risk of incentivising illegal, unreported and unregulated (IUU) tourism (Nielsen and Hodgson-Johnson, 2024) must be a serious consideration when proposing any new model. Alternatively, permits can be allocated equally among existing operators or based on historical patterns ('grandfathering'), employment levels, auction, lottery or some combination of the above. If the 'tourist permit' could be traded among the operators in the tourism industry, there would be some flexibility in how the industry responds to the overall cap on tourist numbers. If allocations are held by tourism operators and an operator decides to leave the industry, they could sell/rent their share to others. This flexibility could, however, result in concentration of ownership within the industry and reduce choice and competitiveness for tourists.

Experience of existing cap-and-trade systems such as the Hunter River Salinity Trading Scheme suggests that there is merit in designing the system such that there is periodic retirement of the existing permits, with permits re-issued and auctioned. For example, auctions could be scheduled every two years with (Hemming et al., 2022) 20% of the permits retiring and re-issued permits auctioned. This approach allows periodic opportunities for new entrants to the industry. Moreover, annual permits re-evaluation could be conducted to address compliance, as permits should be allocated or removed based on adherence to regulatory measures to minimize environmental impact. One of the main benefits of this scheme is its adaptability to newly acquired knowledge. If the overall cap is found to be unsustainable, the pool of permits can be decreased based on evolving scientific evidence, as operators receive a defined share of the permits.

If permits were distributed directly to tourists, allocation processes could include waitlists, lotteries, or markets. Introduction of tradeable permits creates a valuable asset for the holder. Experience from environmental permit markets suggest schemes work best when there are easily accessible information, trading platforms available with minimal transaction costs, and frequent trading. Ideally trading systems are designed to avoid permit hoarding and strategic behaviour that can reduce the efficiency gains of any permit trading system. Recent experience with capping number of tourists on ships to the Galapagos Islands resulted in more ships on shorter tours, demonstrating the care that needs to be taken in designing such systems (Burbano and Meredith, 2021; Benitez-Capistros et al., 2014).

Geopolitics presents a challenge to both the introduction and management of any cap on tourism in Antarctica. The creation of an institution responsible for exclusively managing tourism

and thus distributing permits has been already suggested by some ATCPs. The proposal has failed to reach consensus (India, 2015). The same barriers that Verbitsky (Agrawal, 2003; Ostwald et al., 2021) identifies regarding the establishment of an ATS institution to manage taxes would presumably apply, with the same need to reassure claimants that their sovereignty claims are not threatened, and non-claimants that the new institution does not threaten the status quo. Here, we re-emphasise the need for a centralised coordinating body which can undertake multiple functions in a fair and objective manner. In the Antarctic context, care would need to be taken in the initial allocation of permits, given the dominance of the industry by Western-based operators. The risk of a resurgence of the "Antarctic Question," which was debated in the 1980s in the UN and revolved around the perceived domination of decision-making in the region by an exclusive group of nations, would need to be addressed. Moreover, with new regional geo-political tensions, any institution charged with governing a cap-and-trade system must be equipped to navigate differing views and agendas. More positively, the revenue from auctions of permits might be directed to research, monitoring, mediation, education, and repair of tourist-related damages, or held in trust for the future of Antarctica. However, the questions of how to manage such a trust, how funds might be distributed and where the administering institution would be located geographically would need to be settled.

Market-friction tools

Certification schemes. While membership of IAATO is not a legal requirement within the Antarctic Treaty System, almost all current Antarctic tour operators belong to this organisation, which imposes strict standards upon its members. However, if the Antarctic Treaty Consultative Parties aim to reduce visitor numbers and/or to reduce the impact of current visitors beyond the status quo, then a certification standard would need to be tightened beyond current levels for product differentiation to occur. Whatever standards are imposed, the literature clearly suggests that there must be monitoring and enforcement (which raises the question of by whom); otherwise, the certification could become meaningless to the consumer. Research also suggests there can be program and membership attrition (Buckley, 2020; Dunk et al., 2016), as early adopters choose not to renew. This is partially because of financial and time costs required to maintain certification, and partially because some operators obtain certification but do not stringently adhere to standards, thus lowering the value/benefits of membership for other operators (Buckley, 2020; Dunk et al., 2016).

Nudging. Globally, tourism operators have implemented a range of nudges relating to the use of bed linen, water conservation and sustainable eating options. It is not clear, however, whether such nudges—or nudging more generally—would be able to moderate tourist (or tourism operator) behaviour in a substantive way within the Antarctic.

Discussion

Distribution of tourists

Landing sites are limited in Antarctica and so increasing the potential for impact. Most current destinations are concentrated on or in the vicinity of the Peninsula, mainly due to its proximity to mainland Argentina. However, tourism also occurs in other more remote areas (Figure 2). Diversification of activity types (Figure 3), intensification of tourism (Figure 4), along with increased geographical dispersal over time (Figures 3 and 4) are cause for concern. Tourism diversification with the potential of new, negative impacts requires consideration of cumulative environmental impacts. Activities can have markedly different impacts depending on whether they are marine or land-based, the level of associated noise pollution, the length of the activities

(i.e. snow-shoeing, remote camping trip, etc.). Moreover, the sensitivity of the area (e.g. IUCN classification of species) and the total individual exposure to disturbance play a role in determining the environmental impact of human activities. The map provides a useful visualisation tool. Future research could usefully develop indices (or other) that capture information about tourist activities and impacts at particular sites, thus transforming this figure into one that better depicts actual impact. Such map would ultimately provide the necessary data for the development of a comprehensive conservation planning framework which, in turn, can better identify the most relevant combination of economic instruments and regulatory measure for site-specific conservation.

Forecasts

Rapidly growing numbers and diversification of activities are two of the main concerns expressed by the Antarctic Treaty Consultative Parties (ATCM, 2024). Each year IAATO provides an estimate of the total number of visitors expected in the following season, but predictions over a longer timescale are not attempted. We provided a forecast of the trend in visitor numbers over the next decade that can be anticipated if trips continue on the current trajectory. While forecasting models are subject to error, our results are not improbably high; in fact, is worth noticing that Woehler et al. (2014) forecasted that Antarctic visitors would tally at 120,000 by 2060, a figure that was reached, and surpassed, in the 2023–2024 season (International Association of Antarctica Tour Operators, 2024).

We acknowledge that tourism growth is subject to a variety of broader factors. For instance, longer Austral summers, as a result of climate change, could lengthen the tourist season and shrinking sea ice could open up new areas for cruise vessels (although ice instability could also present safety concerns), potentially further increase visitors' number (Liggett et al., 2017). Alternative theories suggest there may be a gradual decline in accordance with the destination lifecycle hypothesis of Butler (Butler, 2006). A qualitative analysis of Antarctic tourism by Liggett et al. (2017) hypothesized four different scenarios in relation to the future of Antarctic tourism. In the most optimistic scenario, Liggett et al. hypothesize that Antarctic tourism will continue to increase and reach a peak around 2030, in line with our predictions of a growing number of visitors in the next decade. In the other three Liggett et al scenarios, tourism results in environmental degradation, reduced regulation (which attracts more competition across operators) or the development of land-based permanent facilities. The risk is that anthropogenic impact from the industry would represent a tipping point when combined with threats from climate change, a more severe and more complex challenge to address. If our predictions were to actualise, a management instrument that could curb number of tourists, would be a more amenable choice to ensure tourism sustainability (Kubiszewski et al., 2025).

Economic instruments to support Antarctic tourism management

Price-based instruments such as taxes and quantity-based instruments such as cap-and-trade have been shown to yield similar results under strict theoretical assumptions (Weitzman, 1977)—but contextual considerations have been shown to be important in determining actual outcomes on the ground. In wildlife tourism, for example, Mancini et al. (2017) found that, when applied in isolation, codes of conduct and licensing were largely ineffective and inefficient at preventing negative impact on wildlife. In another wildlife-tourism study, Pirotta et al. (2015) found that instruments such as cap-and-trade and time quotas, when supported by taxes and subsidies, were effective tools for minimising tourism impact on wildlife and thus promoting sustainable wildlife tourism.

'Assessment of economic instruments for Antarctica' section highlights the importance of those considerations in Antarctica. Table 1 summarises core insights, providing a contextual overview of both the potential *effectiveness* and the potential *acceptability/suitability* of different economic instruments in the Antarctic. It also identifies core benefits and implementation challenges. Most evident is that no single economic instrument is able to address every issue related to tourism and thus is not likely to succeed in isolation. We thus suggest that a suite of instruments within the context of the development of a tourism management plan be considered in ATCP discussions, including:

- Quantity-based mechanisms to restrict visitor numbers to the region and to sensitive areas in order to control/predict outcomes;
- Targeted tourism taxes on tourism activities;
- Nudges to raise awareness, and to deeply involve tourists and operators in the development and maintenance of a socially, economically and environmentally sustainable industry, most likely achieved via IAATO;
- Industry-based discussions within IAATO membership about whether it is necessary, or desirable, to impose tighter (certification) requirements on operators who take visitors to high impact, or near potentially vulnerable, sites. Rewarding operators who go above and beyond the current requirements is a non-mutually exclusive alternative.

These instruments can complement and/or be instigated by the ATS, but should be developed as part of a more comprehensive ecosystem-based approach, which includes a precautionary approach to prevent serious and irreversible damage (Bastmeijer and Roma, 2004; Fennell and Ebert,

Table 1. Suitability of each economic instruments in the Antarctic environment in relation to their effectiveness and likelihood to be implemented by ATCM members.

Regulatory instrument	Reduce adverse environmental impact	Curb visitors' growth	Efficient management of diverse activities and site-specific impact	Ease of implementation	Main benefit	Main challenge
Taxes & subsidies	✓	✗	✓	Medium	Generates funds to invest in monitoring and green technology	Need of additional institution to manage revenue
Environmental offsets	No net reduction	✗	✓	Hard	Compensates environmental harm in one area, by improving other areas to ensure no net (environmental) loss.	Hard to find alternative places to restore similar ecosystem services
Cap-and-trade	✓	✓	✗	Hard	Caps the number of tourists in sensitive areas	Might incentivise IUU tourism and unfairness in allocation
Certification scheme	✓	✗	✗	Medium	Ensures co-management with industry	Need agreement on certification body
Nudging	✓	✗	Maybe	Easy	Raises awareness	Requires monitoring and enforcement

2004). Additional management tools such as spatial and temporal area management, codes of conduct and regulations, applied to IAATO and non-IAATO members alike, and nudging should also be employed to encompass the range of human activities in the region.

Conclusions

A range of economic instruments have been presented that could conceivably be used in the management of Antarctic tourism, as part of a broader strategy. This paper highlights some of their strengths and weaknesses, considering both the potential ability to control or mitigate negative impacts the potential suitability/acceptability within the Antarctic Treaty System. Research suggests that there can be considerable uncertainty about the ability of economic instruments to effect change. We cannot be sure, for example, that price-based mechanisms will alter tourist numbers and/or tourist behaviours. However, price may aid in raising revenue useful in covering the cost of changing administrative/management processes as well as monitoring and enforcement activities. 'Nudging', a 'softer' instrument, may be deemed most acceptable by industry, but may not, in the end, be able to invoke the substantial changes, required to protect Antarctica from the cumulative impacts of tourism.

Finally, we acknowledge that while our preferred solution—a combination of quantity-based instruments, nudging and tighter certification—may be the most effective strategy, it faces practical difficulties, including the different and possibly contrasting interests, values and political priorities of the Antarctic Treaty Consultative Parties. It is challenging to reconcile environmental conservation with a profitable and fast-growing tourism industry. Natural site-specific vulnerabilities, global environmental phenomena (e.g. climate change), a lack of monitoring and the limitations around the implementation of ATCM resolutions within domestic legislation all contribute to the difficulties of effective tourism management in the Antarctic region. Nonetheless, with Treaty parties recently launching a multi-year process of developing a systematic framework for managing Antarctic tourism, a nuanced understanding of the advantages and disadvantages of various economic instruments will support productive negotiations.

Author contributions

CRediT: **V. Senigaglia**: Conceptualization, Data curation, Formal analysis, Methodology, Resources, Writing – original draft, Writing – review & editing; **D. Hatton MacDonald**: Conceptualization, Formal analysis, Methodology, Project administration, Writing – original draft, Writing – review & editing; **N. Stoeckl**: Conceptualization, Methodology, Resources, Writing – original draft, Writing – review & editing; **J. Tian**: Data curation, Formal analysis, Resources, Writing – original draft, Writing – review & editing; **E. Leane**: Conceptualization, Resources, Writing – original draft, Writing – review & editing; **V. Adams**: Data curation, Formal analysis, Methodology, Writing – review & editing; **R. Baird**: Resources, Writing – review & editing; **A. Boothroyd**: Data curation, Formal analysis, Resources, Writing – original draft, Writing – review & editing; **R. Costanza**: Conceptualization, Resources, Writing – original draft, Writing – review & editing; **E.A. Fulton**: Conceptualization, Resources, Writing – review & editing; **S. Hartman**: Data curation, Formal analysis, Resources, Writing – review & editing; **I. Kubiszewski**: Conceptualization, Resources, Writing – original draft, Writing – review & editing; **H. Nielsen**: Resources, Writing – review & editing; **C.-S. Ooi**: Conceptualization, Resources, Writing – review & editing.

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