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Towards a tipping point? Exploring the capacity to self-regulate Antarctic tourism using agent-based modelling

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ABSTRACT

Antarctica attracts tourists who want to explore its unique nature and landscapes. Antarctic tourism has rapidly grown since 1991 and is currently picking up again after the recent global economic downturn. Tourism activities are subject to the rules of the Antarctic Treaty System (ATS) and the decisions made by the Antarctic Treaty Consultative Parties (ATCPs), but within this context, the industry has considerable freedom to self-organise. The industry is self-regulated by a voluntary member-based group, the International Association of Antarctica Tour Operators (IAATO). Researchers and policy-makers express concern about IAATO's ability to deal with further tourism development and the environmental consequences. This study applies a new approach to understand what affects self-regulation, consisting of a literature review and agent-based modelling (ABM). The review identifies four challenges for self-regulation: operator commitment, tourism growth, operator diversification, and accidents. The ABM simulations help conceptualise the complex concepts and theories surrounding self-regulation. Self-regulation is measured by the capacity of the simulated self-regulatory system to maintain a majority membership at the end of 20 years. The model suggests that a number of the challenges are nonlinear and have tipping points. This approach provides insights that industry officials and policy-makers can use to proactively regulate Antarctic tourism.

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IAATO; agent-based modelling (ABM); self-regulation; Antarctic tourism; simulation; scenario analysis

Introduction

Antarctica comprises the area South of latitude 60 degrees, an area that is increasingly affected by human activities (Tin, Lamers, Liggett, Maher, & Hughes, 2014). Antarctica is remote, fragile, and potentially dangerous with extreme weather conditions. It is both a valuable scientific laboratory (Enzenbacher, 2007) and a unique vacation destination (Berger, 2010; Splettstoesser, 2000; Stonehouse & Crosbie, 1995). Antarctica's key selling point is its wildlands that are perceived by tourists as "pristine" and "untouched" (Haase, Lamers, & Amelung, 2009). Shipborne tourism is the most common means for tourists to travel to and from, and explore, Antarctic wildlands (Liggett, McIntosh, Thompson, Storey, & Gilbert, 2010; Muir, Jabour, & Carlsen, 2007).

Antarctic tourism has grown and diversified considerably over the last two decades, which causes concern for environmental sustainability (Liggett, McIntosh, Thompson, Gilbert, & Storey, 2011; Lynch, Crosbie, Fagan, & Naveen, 2010; Orams, 2010). Tourism can increase awareness of Antarctica's

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Supplemental data for this article can be accessed here.

uniqueness (Headland, 1994; Powell, Kellert, & Ham, 2008), but may also negatively and irreversibly change Antarctica (Enzenbacher, 2007). For example, increased visitor numbers and traffic can increase environmental stress on frequently visited areas or lead to accidents (Liggett et al., 2011; Lynch et al., 2010). Moreover, by visiting biodiverse sites, tourists can increase the risk of alien species being introduced (Chown et al., 2012; Frenot et al., 2005). Scientists and policy-makers are increasingly aware of these impacts and Antarctica's growing environmental vulnerability related to tourism development (Bastmeijer & Roura, 2004; Haase, Storey, McIntosh, Carr, & Gilbert, 2007; Lamers, Liggett, & Amelung, 2012; Splettstoesser, 2000). Antarctic tourism operators are also concerned about increased environmental pressures and degradation (Liggett et al., 2011).

Antarctic tourism poses a unique governance challenge. The Antarctic is not controlled by any single sovereign state; it is a "global commons" (Lamers et al., 2012; Liggett et al., 2010). Parts of Antarctica have been claimed by several nations, but these claims were put on hold when the Antarctic Treaty was signed in 1959. The Antarctic Treaty sets aside the Antarctic for the purposes of peace and science (Headland, 1994; Secretariat of the Antarctic Treaty, 1991). The Antarctic Treaty and related agreements are collectively known as the Antarctic Treaty System (ATS). The ATS is Antarctica's leading governance regime. Decisions are made through annual Antarctic Treaty Consultative Meetings at which 29 Antarctic Treaty Consultative Parties (ATCPs) have voting rights. ATCPs first acknowledged tourism as an acceptable commercial practice in the Antarctic in 1966 (Headland, 1994). Now that tourism has grown much larger, ATCPs experience difficulty actively managing tourism as many countries are involved and no single governing body decides on tourism issues (e.g. Landau, 2011; Molenaar, 2005; Splettstoesser, Landau, & Headland, 2004). The most important tool ATCPs have achieved for regulating Antarctic tourism is the 1991 Madrid Protocol on Environmental Protection, which was ratified in 1998 (Bastmeijer & Lamers, 2013). However, ATCPs disagree on how tourism should be addressed (Bastmeijer & Lamers, 2013; Enzenbacher, 2007) and the ATS follows, rather than leads on tourism issues (Bastmeijer & Roura, 2004; Haase et al., 2007). Some of the ATS's limitations in regulating tourism stem from Antarctica's unique international status (Enzenbacher, 1995), the need for consensus among ATCPs that slows decision-making and implementation (Bastmeijer & Roura, 2004; Lamers et al., 2012; Liggett et al., 2010), and lack of knowledge on Antarctic tourism issues (Enzenbacher, 2007). As a result, regulations for tourism are often not legally binding (Amelung & Lamers, 2006; Haase et al., 2009). Decision-making and implementation have been ad hoc and sporadic instead of offering long-term comprehensive governance strategies (Amelung & Lamers, 2006; Bastmeijer & Roura, 2004; Lamers et al., 2012). More strategic approaches to managing Antarctic tourism, aimed at developing a long-term vision, have been proposed as an alternative (Bastmeijer & Roura, 2004; see also Tin, Liggett, Maher, & Lamers, 2014).

In response to the ATS-level inertia, the International Association of Antarctica Tour Operators (IAATO) has emerged as an industry-led self-governing body in charge of sustainable Antarctic tourism (Splettstoesser, 2000). A group of seven operators established IAATO and the Antarctica Tour Operators Guidelines for environmentally acceptable practices in 1991 (Landau & Splettstoesser, 2007b). Currently, most operators are IAATO members (IAATO, 2015a), which allows IAATO to act as a single and clear contact point for tourism issues (Haase et al., 2007). IAATO has performed well in the past, is proactive, and fosters participatory collective decision-making (Haase et al., 2007, 2009). Tour operators collaborate because they share a common goal of catering to tourists' expectations of visiting a pristine environment by avoiding crowding and environmental damage (Splettstoesser, 2000). IAATO coordinates a ship scheduler to avoid overcrowding sites with their simple statement 'one ship, one place, one moment' (IAATO, 2015b). This scheduler enables tourism operators to continue selling a seemingly undiscovered Antarctica. Non-members can receive the same benefits and are invited to share their data with the scheduler. IAATO's goal of sustainable tourism in the Antarctic (Lambert, 2007) has given IAATO a positive public image for its environmental practices (Splettstoesser, 2000). IAATO also actively interacts with ATCPs, environmental organisations, and experts (Landau & Splettstoesser, 2007b), while also stimulating visitor education to preserve the unique environment (Splettstoesser et al., 2004). In general, IAATO membership provides many benefits, such as proof of environmental commitment for operators, ship scheduling, administrative services and communication, a positive name by association, and a voice in tourism-related decision-making (Haase et al., 2009).

It is clear that Antarctica's well-being and the sustainability of tourism rely on IAATO's voluntary system of self-governance. Real concerns persist on whether such a precious resource can be entrusted to an industry that profits from sharing it with more people (Liggett et al., 2010). IAATO recognises the need to adapt and change operations to deal with continued growth in Antarctic tourism (Lambert, 2007) and is concerned about how non-member operators affect IAATO's ability to self-regulate (Haase et al., 2007). Industry and government decision-makers have the responsibility to ponder what Antarctica's future should look like (Bastmeijer, 2011). Once changes take place, they may be too difficult to reverse, thus proactive management may prevent major problems. Haase et al. (2009, p. 426) highlight asking "'what-if' questions before they turn into 'why' questions" so that researchers can "pro-actively investigate design parameters for appropriate regulatory tools".

Previous studies have used literature and document analysis, interviews, Delphi studies, and scenario analysis to study strategic Antarctic tourism governance questions that have been on the table for decades (Lamers et al., 2012). This study develops a new approach to explore the limits of self-regulatory systems in sustainable tourism with IAATO, as a case study. Its specific focus is on IAATO's ability to maintain majority membership among operators so as to keep the leading position with respect to the industry's self-organisation. The research approach combines a literature review with agent-based modelling (ABM). The review identifies the challenges IAATO's self-regulation regime faces and key discourses on how these challenges may impact IAATO's ability to self-regulate by maintaining majority membership. The two key contributions of our study are in formalising these known and presumed relationships and in quantifying some of the scenarios that researchers have presented in future-oriented studies on Antarctic tourism.

As a first step, a conceptual framework is developed on how a variety of challenges are known or thought to impact operators. The conceptual framework is subsequently operationalised and evaluated using ABM (for more details, see the Technical Annexe, which can be found in Supplemental Data in the online version of this paper). ABM facilitates experimentation to proactively explore how different factors and changes affect the capacity to self-regulate. The agent-based model simulates how individual actor's decisions (and interactions) lead and respond to changes in various (future-oriented) scenarios. The main objective is to explore how different changes affect IAATO's ability to maintain a majority of operators as members in the self-regulatory system. Membership numbers therefore constitute the model's single most important indicator. For model design and implementation, ample use has been made of relevant theoretical insights (Olson, 1965; Ostrom, 2005), observed empirical relationships in the key scientific literature (e.g. Crosbie & Splettstoesser, 2009; Haase et al., 2009; Landau & Splettstoesser, 2007b; Liggett et al., 2011) as well as IAATO documents and statistics. IAATO documents determine start-up values, operator characteristics, and potential growth scenarios (IAATO, 2013, 2014, 2015a, 2015b).

The paper is structured as follows. First, the literature pertaining to IAATO's self-regulation challenges is thoroughly reviewed. Particular emphasis is given to the ways in which these challenges are known or believed to change operators' propensity to become or remain a member. The Methodology section provides a description of the agent-based model. The Results section reports on the implications of a variety of scenarios. The Discussion section puts the findings into the context of the wider Antarctic tourism and agent-based modelling literatures. The Conclusion section highlights the main findings and gaps in current knowledge, and suggests promising avenues for further research.

Review of Antarctic tourism self-regulation challenges

IAATO has a strong environmental track record and its standards currently comply with the Antarctic Treaty stipulations (Crosbie & Splettstoesser, 2009; Landau & Splettstoesser, 2007b). Nevertheless, researchers (e.g. Haase et al., 2007, 2009; Liggett et al., 2010; Stewart, Draper, & Johnston, 2005) question whether IAATO can maintain its leading role as Antarctic tourism further develops. This is worrisome, since alternatives are lacking for self-regulation as the dominant governance structure (Haase et al., 2009). Researchers express the urgent need to understand the limits of the current self-regulatory regime (Liggett et al., 2011) and to create a strategic direction and coordination for tourism (Enzenbacher, 2007) because tourism developments are difficult to reverse once they occur (Amelung & Lamers, 2006).

IAATO, and its ability to self-regulate, relies on operator members' goodwill and commitment. It needs to represent the majority of operators to remain credible (United Kingdom, 2004). So far, operators have greatly depended on each other for commercial success, and this interdependency has helped to maintain self-regulation (Lamers et al., 2012; Ostrom, 2005). However, as new operators enter the Antarctic tourism market, Lambert (2007) questions whether existing members are willing to expend more effort dealing with situations brought on by more diverse interests.

IAATO also faces the challenge of non-members and free-riding. Currently, most non-members are yachts and small polar expedition companies (Haase et al., 2009; Orams, 2010). Non-members are unregulated, may be unaware of environmental responsibilities, and harm IAATO's image by damaging the environment (Haase et al., 2009). Non-members benefit from IAATO's services (e.g. ship scheduling and safety) without being required to follow IAATO's guidelines (Amelung & Lamers, 2006; Antarctica New Zealand, 2000). Free-riding has the potential to weaken the self-regulatory system because IAATO cannot legally exclude non-members from accessing Antarctica (Molenaar, 2005). Too many free-riders lower IAATO's legitimacy to self-govern and may lead to the ATS displacing IAATO (Haase et al., 2009; United Kingdom, 2004).

This study sheds light on the influential factors in individual tour operators' decisions to become, remain, or cease to be IAATO members, and on the impacts that a range of challenges might have on these decisions. After all, the (interdependent) individual decisions will determine total IAATO membership, and eventually IAATO's ability to lead the tourism industry's self-regulatory regime. The key literature sources on IAATO discuss a range of factors that might affect membership, including industry growth and diversification, accidents, institutional interplay, and global fuel prices (Haase et al., 2009; Landau & Splettstoesser, 2007a, 2007b). This article cannot cover the full spectrum of factors, but focuses on those related to development and uncertainty that may affect tour operators' decision-making and IAATO membership: commitment, more operators, diversification of operator interests, and accidents. These four major issues are analysed in the following sections. For the sake of simplicity, in this paper, we will focus on ship-based tourism only, and disregard the fact that IAATO includes land-based operators as well.

Commitment

Members' commitment and social pressures are essential to preventing operators from free-riding. Ostrom (2005) identifies eight design principles for robust common pool resources management. The principles relating to commitment are collective-choice arrangements, proportional equivalence of costs and benefits, and monitoring. In short, members of self-regulatory systems will show greater commitment if they have the possibility to collectively define and implement the rules for engagement and resource use, estimate the benefits of collaboration to be higher than the possible costs, and have the possibility to observe the behaviour and impact of other members (for more details, see Haase et al., 2009). Commitment is heterogeneous (Davis, 1995); members have distinct experience levels, have different preferences for collective-choice arrangements, are not systematically monitored, and experience different benefits (Haase et al., 2009).

Experience is an important precursor to commitment (Antarctica New Zealand, 2000; Liggett et al., 2010). New IAATO members may not share the same commitment level and aptitude as original members (Amelung & Lamers, 2006). Originally, members were small-scale operators of small ships; vessels carrying more than 400 passengers could not join IAATO (Haase et al., 2009; United Kingdom, 2004). Currently, operators are distinguished by four main vessel types: yachts (1–11 passengers), small ships (12–200 passengers), large ships (200–500), and cruise ships (more than 500). Only 100 passengers can simultaneously land onshore and cruise ships are prohibited from landing (i.e. cruise-only expeditions).

IAATO's self-regulatory system depends on operators' goodwill (Haase et al., 2009; Liggett et al., 2010) and operators' willingness to participate and support IAATO's voluntary guidelines (Landau & Splettstoesser, 2007b). IAATO has no authority to impose legal restrictions or limit companies' operations, and relies on market authority and social pressure (Landau, 2011). Meetings are held throughout the year and are the glue that binds members and maintains commitment levels. Olson (1965) claimed that no self-interested person would contribute to a public good unless participant numbers were small and coercion or some other incentive caused individuals to support the common interest. Operators generally have the same goal of providing tourists with an exclusive experience in Antarctica's wildlands (Haase et al., 2009) and will remain interdependent as they work in unique and isolated conditions (Lamers et al., 2012). Furthermore, IAATO has an established reputation. Thus, operators can demonstrate their commitment to preserving Antarctica's environment most easily by associating with IAATO. Members are encouraged to participate in decision-making and policy-making, but inevitably, some members take more initiative than others (Haase et al., 2009).

Members constantly monitor each other, which creates social pressure (Haase et al., 2007). Social pressure and self-monitoring, instead of systematic monitoring, are used to motivate members to voluntarily uphold IAATO's image and guidelines (Haase et al., 2009). Little is known about charter boats and yachts and their commitment level to the ATS environmental protocol (Orams, 2010; Splettstoesser, 2000). Yachts are more difficult to monitor than other ship types. Thus, yacht operators require high levels of personal commitment to become a member as they are not easily targeted by social pressure to conform.

Members expend considerable effort (Enzenbacher, 1995) reporting, planning, attending meetings, and training (in terms of time, effort, and money) in order to realise membership benefits (Haase et al., 2009). IAATO continuously broadens its scope, which requires increased member commitment to implement its programme (Enzenbacher, 2007). A broadened scope makes it more difficult to balance different individual interests. Thus, IAATO's strength of getting competitors to agree on a general strategy (Haase et al., 2007) could turn into a weakness. Moreover, not all members receive the same benefits. Cruise ships, for example, are not allowed to land, an opportunity which is very attractive to tourists (Wright, 2008). New members are more likely than established members to determine that membership costs outweigh the benefits, and leave IAATO as they do not share the same initial commitment or social norms (Haase et al., 2009).

More operators

Scientists and industry experts expect that the presence of more operators will increase site congestion (Amelung & Lamers, 2006; Liggett et al., 2011; Stonehouse & Crosbie, 1995). Little is known about the long-term consequences of Antarctica's further tourism growth (Lamers et al., 2012) or when tourism growth will level off and visitor numbers will become stable. Since the mid-1990s, the tourism industry has experienced unprecedented growth, from around 11,000 visitors in 1995 to over 40,000 in 2008−2009 (Lamers et al., 2012). Tourist numbers declined following the global economic crisis; however, visitor numbers have begun to recover in recent years to approximately 35,000 (IAATO, 2015a).

Supply is the limiting factor in Antarctic tourism development; although high costs are a constraint, demand appears fairly price-inelastic (Snyder, 1997; Snyder & International Ecotourism Society, 2007). Historically, two-thirds of tourists come from four countries: USA, Germany, the UK, and Australia (Enzenbacher, 2007). However, in the booming economies of China, India, and Brazil, disposable income and visitor numbers are expected to continue growing (Enzenbacher, 2007; Lamers et al., 2012). Diversification of tourists and operator countries may make tourism more difficult for IAATO to manage.

Earlier companies operated small-scale ships and catered to specialist clients (Liggett et al., 2011). Researchers anticipate that larger ships will be used to cater to increased tourism demand (Frenot et al., 2005; Liggett et al., 2011; Snyder, 1997). Along with growing numbers of larger ships, yacht numbers are increasing (see IAATO, 2015a).

Researchers question whether IAATO can manage the upcoming visitor growth (Haase et al., 2009). Increasing tourist numbers and non-members could affect IAATO's unity (Haase et al., 2007). When IAATO was managing a smaller number of similar operators, it already needed many strategies and techniques to ensure that members were following the guidelines (Landau & Splettstoesser, 2007b). Self-regulating challenges occur when more operators participate in IAATO (Haase et al., 2009; Ostrom, Burger, Field, Norgaard, & Policansky, 1999).

Operator diversification

Access barriers for tourism operators are high because of the planning, infrastructure, and experience needed to operate in Antarctica (Landau & Splettstoesser, 2007a). Ships need to cross long and dangerous stretches of ocean to reach Antarctica. Unsurprisingly, approximately 90% of Antarctic tourism is concentrated in coastal areas surrounding the Antarctic Peninsula and island of South Georgia because of relatively easy access (Stonehouse & Crosbie, 1995). Improvements in infrastructure and equipment can greatly increase access, enabling operators with less commitment to conserving Antarctic's wildlands to offer tours more easily in Antarctica (Splettstoesser et al., 2004).

Yachts and cruise ships have increased access to Antarctica and their numbers are growing (Orams, 2010). Although Antarctica as a mass tourism destination may seem farfetched, the transition to mass tourism has already occurred in other vulnerable regions, such as the Galapagos Islands and African wildlife parks (Liggett et al., 2011). Large cruise operators may drive out smaller operators because they can offer cheaper products and many additional services (Splettstoesser et al., 2004), which may pressure IAATO to support mass tourism (Haase et al., 2009). Nonetheless, policy directed at cruise ships (the ban on the heavy fuel oil [HFO] that such ships use, which was implemented in 2011) has hampered their growth (IAATO, 2015b). The HFO ban, along with the recession, lowered the number of cruise ship passengers and cruise ship vessels active annually (IAATO, 2014). Whether HFO restrictions will continue limiting cruise ship growth as the economic situation changes is uncertain.

The lack of legal boundaries to exclude non-members poses a challenge for IAATO (Haase et al., 2009). Countries that ratified the Antarctic treaty are legally bound to follow conduct guidelines South of latitude 60 degrees, while other countries are not (Enzenbacher, 1995). Commercial cruise ship companies tend to choose flags of convenience and can, therefore, avoid legal regulation (Wright, 2008). As a result, IAATO will encounter more difficulty incorporating, responding, and representing members' decisions as membership grows and diversifies (Haase et al., 2009). Moreover, diverging interests impedes IAATO's ability to reach collective decisions (Lamers et al., 2012). Thus, operator diversification through increased access poses real challenges for IAATO to self-regulate.

Accidents

Accidents are inevitable. Records indicate accidents are "an undesired, but far from unusual, companion of adventure tourism operations and shipping" (Liggett et al., 2011, p. 358). Most accidents are small and unintentional (Haase et al., 2007). However, serious accidents can lead to far-reaching consequences, such as environmental degradation, human casualties (Liggett et al., 2011), and, consequently, a less favourable public opinion of IAATO and the existing ATS regime (Enzenbacher, 2007). Accidents have also hindered tourism growth (Liggett et al., 2011; Muir et al., 2007) and activity levels. Uncertainty exists about what the consequences of future accidents, especially if non-member operators are involved (Enzenbacher, 2007), will be on operators' activity levels and to what extent tourism growth will be affected.

Accident risk is expected to rise as tourist numbers and shipping traffic increase (Liggett et al., 2011). For example, pressure to meet time slots for visiting key sites may lead to more accidents (Wright, 2008). Further, large safety risks emerge when large ships of over 500 passengers operate in Antarctic waters (Bastmeijer, 2011) as rescue procedures are more complicated with higher passenger numbers and many large (cruise) ships are not equipped with a double hull (Wright, 2008).

Lowering the risk of accidents is costly and involves extensive training and contingency planning (Lamers et al., 2012). Operators need to carefully plan their emergency strategies because of Antarctica's physical remoteness and harsh and unpredictable environmental conditions (Enzenbacher, 1995; Muir et al., 2007). Experienced operators are better prepared for these conditions (Enzenbacher, 2007). IAATO members arrange mutual assistance agreements (Haase et al., 2009), take operational precautions, and learn safety protocols (Liggett et al., 2011; Splettstoesser, 2000). They are better prepared, more aware of safety issues, and, therefore, are less likely to incur accidents than non-member operators.

Summary of the literature findings

The literature highlights how self-regulation challenges relate to individual operators. First, the operators' commitment is heterogeneous and affected by their experience, the group dimension, operator type, and their perception of membership benefits versus costs. Growth makes participating in IAATO difficult for members. Diversification enables operators with less experience, different goals, and less commitment to enter the market. Moreover, accident risks are increasing and require more experience, commitment, and coordination among members to prevent. Accident events affect membership costs and operators' activity level. The next section describes how these challenges are modelled.

Methodology and scenarios

Agent-based modelling (ABM) portrays actors' heterogeneity, nonlinear individual behaviour, and interactions among actors (Bonabeau, 2002). ABM helps examine emergent patterns – in this case, membership in a self-regulatory system – which are not obvious from individual actors' decisions (Gilbert & Terna, 2000). In this paper, operators' behaviour is emulated applying simple rules using NetLogo 5.0.4 software. The model description uses elements of the Overview Design Concepts Details (ODD) protocol while avoiding technical jargon. The ODD protocol was specifically developed for describing agent-based models as well as enabling others to reproduce the model and its findings (see Grimm et al., 2006, 2010). A full version of the ODD model description is provided in Supplemental Data in the online version of this paper. Here, the overarching conceptual framework is outlined, the actors and major concepts of commitment, accidents, and membership are explained, and subsequently, the scenarios are described.

Conceptual framework

This model explores the self-regulatory success of a simulated IAATO (referred to as sim-IAATO), given a number of challenges. The actors simulated in the model are ship-based tour operators (referred to as sim-ops). The indicator for self-regulatory success is membership coverage, the percentage of sim-ops who are members, at the end of the simulated period. The model takes the season 2013–2014 as its base year, and has a 20-year temporal timeframe (2013–2034). Time in the simulation is not continuous but discrete. Every year (four-month season) consists of eight time steps.

At the beginning of each time step, sim-IAATO's collective image is updated and new sim-ops may be added (see Figure 1). Image, in this context, is defined by a combination of how sim-IAATO

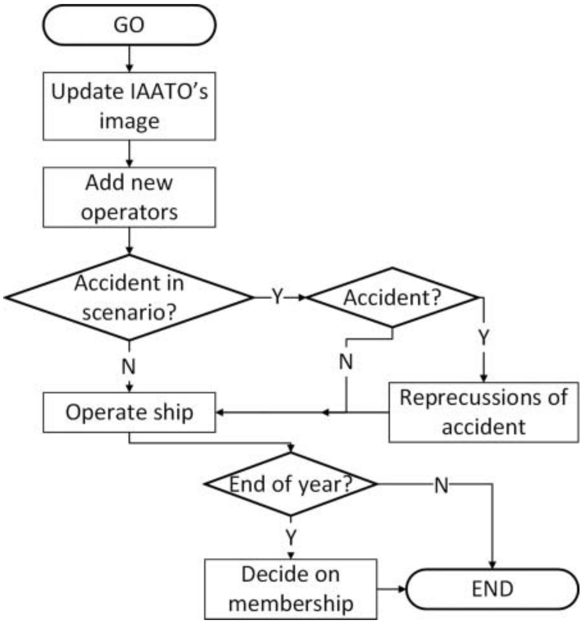

Figure 1. Conceptual framework.

performed in the past (goodwill) and how much influence it currently has, as expressed by membership coverage. The maximum number and type of sim-ops added during a scenario are pre-defined by the simulation user with the help of sliders. Once the maximum number of new operators is reached during a simulation, no further operators are added. The user also determines whether accidents are included in the simulation (with a slider), the level of accident risk (slider), and what are the costs (slider) when they do occur. Then the simulation determines whether an accident occurs in every time step. If an accident does occur, both the sim-op involved and other sim-ops face repercussions. After finishing these system-level updates, each actor performs a series of actions. The order of these actions is fixed, whereas the order of the actors is randomly determined. First, each sim-op tries to operate. If another ship obstructs a sim-op, the sim-op changes course to operate next time step. Otherwise, sim-ops sail (move one step) and increase activity level (by one) and commitment level based on experience. At the end of each year (once every eight time steps), membership decisions are made, after which the group effect for members and the non-member effects are calculated and sim-ops activity levels are reset to zero unless they are below zero. In that case, activity level remains the same, as it is a repercussion of an accident.

Actors

Sim-ops' objectives are to operate, maximise their personal benefits (by either being a member or not), and reach their desired activity level. Activity level is the number of times a sim-op cruises in a season (0:8). Desired activity level is the number of cruises a sim-op wants to have in a year. Desired activity level is heterogeneous, but is set within parameters based on the sim-op's ship type. These parameters are based on historical tendencies of operators' ship types (IAATO, 2015a). Actors may differ from each other on six features: ship type, decision weights (based on a cost−benefit analysis), membership (yes/no), desired activity level, activity level (0:8) (this value can be negative in accident scenarios), and commitment level (0:1.00) (see Table 1). Ship type, decision weights, and desired activity level remain constant throughout the simulation, whereas membership, activity level, and commitment levels are dynamic.

Table 1. Key features per operator type.

	Yachts	Small ships	Large ships	Cruise ships
Initial operators in 2013	31	23	5	4
Initial members in 2013	18	22	4	4
Members since before 2003	2	12	2	2
Decision weight: commitment	≥70%	≥60%	≥50%	≤30%
Decision weight: image	≤30%	≤40%	≤50%	≥70%
Desired activity level	[1−8]	[4−8]	[4−8]	[1−2]
Cost per incident	50%	50%	100%	100%

In 2013−2014, 44 member operators were active and 50 were listed in either IAATO's overviews or membership page (IAATO, 2013, 2014, 2015a). Two members of the 50 have not been active for more than five years and were not included in the model. Due to uncertainty of the number of non-member operators (apart from references to non-member yachts), the model includes 13 non-member yacht sim-ops, one non-member small ship sim-op, and one large ship sim-op. Initialisation values use 2013 as the base year with a total of 63 sim-ops present of which 48 sim-ops are members (see IAATO, 2013, 2015a, 2015b). These numbers remain the same at the beginning of every simulation. The different operator types are visually represented by different ships. For operators with more than one ship type, we used the operator's most commonly used ship type. New sim-ops added to the simulation are non-members, have an initialised random commitment level (0.35:0.50), start in a random location, and have their desired activity level and decision weights set up within the parameters of their ship type.

Commitment

Sim-ops' commitment is influenced by three factors: experience (positive factor), group size (negative factor), and decision not to be a member (negative factor). Experience pertains to how long sim-ops have cruised in Antarctica, how active they are, and whether or how long they are sim-IAATO members. Past experience is indicative of commitment level (Antarctica New Zealand, 2000). Past experience gained before 2013−2014 is calculated based on how many years operators have been members. When sim-ops operate (are active), their commitment level increases. The increase rate depends on a pre-determined maximum-activity-effect-on-commitment slider value, their desired activity level, and whether they are members. Sim-ops with higher desired activity levels as well as sim-IAATO members have a higher increase rate, where the maximum activity effect is twice as strong for members as for non-members.

Group size can negatively affect sim-ops' commitment levels. Members' commitment is not affected as long as the optimal group size (based on Olson, 1965) has not been exceeded. When the group size exceeds a pre-selected optimal group size (slider), members' commitment decreases as they participate and contribute less to the group (i.e. group effect on commitment). The model uses two different methods to parameterise the group effect's decrease rate: a conservative group effect and a progressive group effect. The conservative group effect assumes a constant decrease rate, which is determined by a factor (using a slider), for each new member above the optimal group size. The progressive group effect assumes the decrease rate grows proportionally with each additional member above the optimal group size. When sim-ops decide to remain non-members or leave sim-IAATO, their commitment decreases as they have consciously decided not to participate.

Membership decisions

Sim-ops can freely decide on sim-IAATO membership; no factors prevent them from joining or leaving. Membership decisions are based on Ostrom's (2005) principle that the benefits of being a member of a collective agreement need to be proportional to the costs thereof. Sim-ops use cost−benefit analysis (see Supplemental Data in the online version of this paper) to predict whether being a sim-IAATO member is beneficial for them. The only item on the cost side is membership costs, which are the same for all sim-ops (slider 0:1.00). According to the literature, there are two types of benefits of being associated with IAATO: demonstration of personal commitment to the environment and benefits by associating with IAATO's image (i.e. social pressure) (see Table 1) (e.g. Haase et al., 2009).

The decision weights of these two benefits are heterogeneous (add up to 1), but are set within parameters based on sim-ops' ship types. Yachts are not so visible internationally and, therefore, put more weight on commitment than on sim-IAATO's image. Cruise sim-ops, however, are exposed to international criticism so that sim-IAATO's image has more weight in their cost−benefit analysis. Large ship sim-ops are also susceptible to international criticism, but place less weight on image than cruise ship sim-ops. Small ship sim-ops are core members and put more weight on commitment.

Moreover, the model assumes that if a non-member's activity level is below his or her desired activity level, a positive decision on membership is more likely. Sim-IAATO controls tourism activities in Antarctica to a certain extent, for example through the online scheduler. Therefore, sim-ops can improve their activity levels through membership (e.g. Haase et al., 2009).

Accidents

The probability of a particular sim-op incurring an accident is composed of a general risk factor and the sim-op's individual accident proneness. The general risk factor is pre-determined by the simulation user, with a higher risk factor implying a higher general likelihood of accidents. Sim-IAATO membership, experience, and a high desired activity level reduce a sim-op's accident proneness (e.g. Liggett et al., 2011). Accidents have repercussions for all sim-ops. Activity levels are lowered for a year, with greater reductions for the sim-op involved in the accident, and membership costs increase for the rest of the simulated period (see Table 1, and the Technical Annexe in Supplemental Data in the online version of this paper). Repercussions are more severe if the accident affects a large ship or a cruise ship.

Scenarios

Experiments using Netlogo 5.0.4 BehaviorSpace varied parameters according to scenarios for (1) commitment, (2) growth, (3) operator diversification, and (4) accidents. These scenarios are expanded below. The test output is sim-IAATO membership coverage at the end of 20 years (2034). Each value for each variable was tested 40 times. Unless otherwise indicated, the values used for each variable are the same as in the base scenario, which was set after a process of corner testing, sensitivity testing, and calibration (see the Technical Annexe in Supplemental Data in the online version of this paper). The base scenario reflects the idea of limited tourism development that retains the core operator type of small ships without growth and accidents.

Changing levels of commitment

Three model variables were tested for their influence on membership coverage: (1) experience, (2) optimal group size, and (3) membership cost. The progressive group effect was applied throughout. The tests helped specify the base scenario as well as analyse the underlying concepts guiding the model: experience as a precursor for growing commitment, based on empirical (Antarctica New Zealand, 2000) and theoretical literature, such as Olson's (1965) theory of collective action and Ostrom's (2005) basic principles for common pool resource management.

Growth scenarios: impact of new operators

Membership implications of three growth scenarios are explored, relating to growth in (1) small ships, (2) yachts, and (3) cruise ships. Scenario (1) represents a continuation of small-scale tourism (Liggett et al., 2011). Scenario (2) analyses how growing yacht numbers, which are the most difficult for IAATO to monitor, affect sim-IAATO membership (Haase et al., 2009). Scenario (3) explores the expected trend towards larger ships (e.g. Landau & Splettstoesser, 2007b). Already in the beginning of the 2000s, the cruise industry considered Antarctica a lucrative destination and was ready to deploy 20 more ships if demand would allow (IAATO, 2014). However, to date, cruise ship growth has been limited. All growth scenarios maximise the probability that operators are added to ensure that the maximum number desired for the scenario is reached within the 20 year timeframe. Both the conservative and progressive group effects are applied to each scenario.

Diversification of operator interests

These scenarios investigate whether diversifying interests and moving away from traditional operator types (small ships) affect sim-IAATO membership. The scenarios consider a near doubling of operators compared to the peak season of 2007−2008 (inspired by Haase et al., 2009): fifteen yachts, ten small ships, three big ships, and three cruise ships are added by default. The impact of increasing diversity is explored by varying the number of yachts (1) and cruise ships (2) relative to the default scenario. These scenarios are run with the conservative group effect.

Impact of accidents

The experiments in this category consider the implications of accidents for sim-IAATO membership, addressing concerns about increasing numbers of incidents (Liggett et al., 2011). First, this is done in a no-growth setting to explore the influence of increased accident risk (1). Next, growth is taken into account. Researchers question what would happen to IAATO if larger passenger vessels caused accidents (Enzenbacher, 2007; Liggett et al., 2011). To address this question, a moderate-cost, moderate-risk accident is combined with cruise ship growth (2). Both accident scenarios use the conservative group effect to highlight the impact that accidents have on sim-IAATO membership.

Results

This section reports on the results from the model simulations. Please be reminded that the study aims to explore rather than predict, and that there is a clear distinction between sim-IAATO and the real IAATO and between the sim-ops and the real tourism operators. The figures show the membership coverage at the end of the 20-year simulation period (2034).

Commitment level scenarios

The larger a sim-op's activity effect (i.e. the more active it is, the more its commitment grows) on commitment (1) is, the more members sim-IAATO is able to retain in 20 years. Optimal group size (2) has a clear and strong effect on membership coverage (see Figure 2). If optimal group size is set to values below 20, membership coverage is minimal. If, on the other hand, group size is set to values over 60, membership coverage is nearly complete. Between these two thresholds, membership coverage rises with optimal group size.

For intermediate levels of membership cost (3) (roughly between 0.2 and 0.6), membership coverage is stable at around 80% (see Figure 3). For lower and higher cost levels, there is a strong negative relationship between cost and membership coverage. For levels in excess of 0.9, membership coverage is minimal.

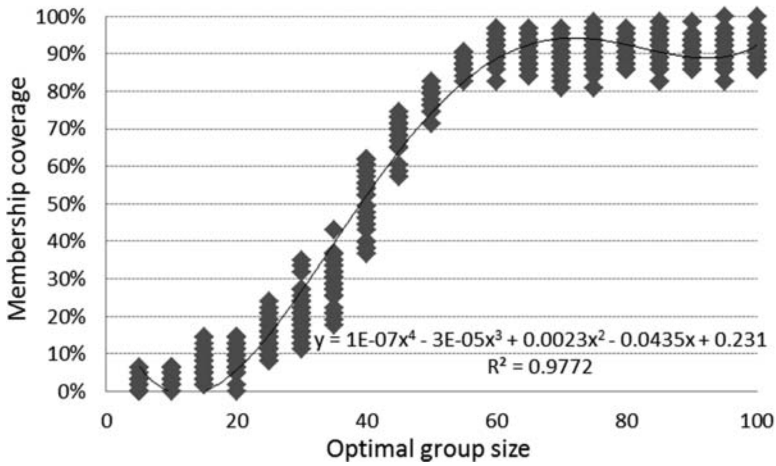

Figure 2. Membership coverage in 2034 as a function of optimal group size.

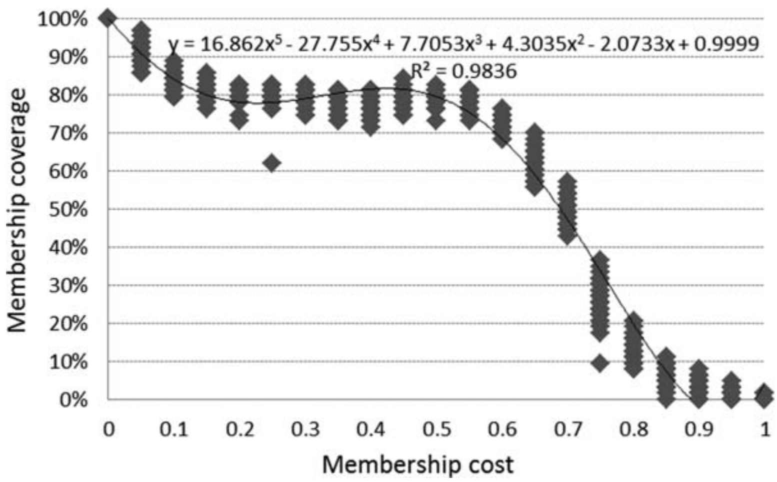

Figure 3. Membership coverage in 2034 as a function of membership cost.

Growth scenarios

Growth in the small ship segment (scenario 1) lowers sim-IAATO's ability to maintain members, regardless of the strength of the group effect. Nevertheless, the strength of the group effect does have a clear impact on the rate at which members are lost. For the progressive group effect, membership coverage decreases by almost one percent point for every sim-op added to less than 50% when 32 small ship sim-ops are added (see Figure 4 in Supplemental Data in the online version of this paper). In contrast, for the conservative group effect, majority membership coverage is easily maintained at around 75% in 2034 (see Figure 4). Members are lost at much lower rates (0.35% point per sim-op added); moreover, the statistical relationship between numbers of small ships added and membership coverage is relatively weak ($R^2 = 0.43$ for conservative versus $R^2 = 0.84$ for progressive group effect).

Similar results are obtained for yacht-led growth (scenario 2). Increases in the number of yachts result in decreasing membership coverage, but the strength of this relationship depends on the assumed strength of the group effect. However, the differences are smaller than in the small ship sim-op scenario. Final membership coverage ranges from around 50% using the progressive group effect to around 65% for a conservative effect (see Figure 5 in Supplemental Data in the online version of this paper). Interestingly, in the yacht sim-op scenario, variability in simulation results is higher in the progressive-estimate case than in the conservative-estimate case.

Assumptions about the strengths of the group effect are particularly critical for the scenario of cruise ship-led growth (scenario 3). When a conservative group effect is assumed, sim-IAATO remains in the majority (see Figure 6 in Supplemental Data in the online version of this paper). In fact, the number of cruise ship sim-ops added has no discernible effect on membership coverage. When a progressive group effect is assumed, simulation results bifurcate for runs in which 10 or more sim-ops are added (see Figure 6). Results cluster in groups; the medians of which are around 35% point apart in terms of sim-IAATO membership coverage. The high-coverage cluster suggests that sim-IAATO will maintain clear majority coverage, whereas the low-coverage cluster suggests that coverage will drop to 20%−30%.

Diversity scenarios

Greater diversity and adding more yacht sim-ops (scenario 1) has a negative impact on sim-IAATO membership (see Figure 7 in Supplemental Data in the online version of this paper), but majority membership coverage is maintained, assuming a conservative group effect. The variability in the results is limited ($R^2 = 0.82$). Increasing diversity and adding more cruise ship sim-ops (scenario 2) only has a small impact on sim-IAATO's membership, assuming a conservative group effect. However, when the decrease rate used for the conservative group effect is larger or the progressive group effect is used, member diversity results in a loss of sim-IAATO's majority.

Accidents scenarios

The influence of accidents on membership (scenario 1) greatly depends on the level of accident risk. At a low risk level (1%), sim-IAATO maintains a majority (see Figure 8 in Supplemental Data in the online version of this paper). At a risk levels higher than 7%, sim-IAATO's membership coverage is less certain. Adding cruise ship sim-ops (scenario 2) increases the impact of accidents on sim-IAATO membership coverage. In the medium-cost, medium-risk scenario (see Figure 9 in Supplemental Data in the online version of this paper), sim-IAATO runs a considerable risk of losing majority coverage.

Discussion

Our results suggest that the self-regulatory system for tourism in the Antarctic can be destabilised by a range of plausible developments in the tourism sector. Changes in commitment, the number of operators, the diversity of operators, and the frequency of accidents may all push membership coverage of the self-regulatory body IAATO below the majority level. Two underlying factors are found to be crucial for model results: optimum group size and membership cost. Group size affects commitment, coherence, and manageability: large groups operate less effectively (Olson, 1965; Ostrom, 2005). Optimum group size refers to the maximum group size with which effective collaboration is still maintained. The specification of optimum group size and membership cost both impact modelled membership coverage in a strongly nonlinear way. Below certain threshold values and beyond certain other threshold values, their impact is minimal, whereas between these thresholds, the factors' impact is strong.

The position of these thresholds is highly uncertain. The results show that different specifications yield very different results. Uncertainty of individual-level mechanisms is one of the main challenges of ABM (Grimm et al., 2005). In the case of the self-regulatory regime in Antarctica, theory suggests that group size effects are likely at some point, but no empirical evaluation appears to exist of how this mechanism works, and how strong it is. Alternative interpretations were tested, with widely different results. Knowledge on the influence of membership costs is equally limited. No studies seem to be available that compare the benefits that tour operators associate with membership to the actual or perceived costs. More in general, the availability of (semi-)quantitative data to specify and parameterise the model was limited. The highlighted uncertainties in the implications of individual challenges, such as growth or changes in commitment, are likely to be amplified in situations where challenges occur simultaneously. The tests of these effects are limited in the current study.

Model uncertainty, or structural uncertainty, is another major source of uncertainty in model results. Any model represents a simplification of reality – in this case, the complex decision-making process of Antarctic tour operators. This process is not well understood, so that important factors and relationships may have been missed. For example, the model does not include the decision to stop operating, which may have important effects on outcomes. In general, the mechanisms and factors implemented in the model are typically conservative, static, and only explain some observable feedbacks as many remain unknown. The observed changing patterns in the literature provide only a fragmented understanding of the underlying mechanisms.

The reader should realise that the model is exploratory and not predictive. Care should be taken not to confuse reality with modelled simulations (as we have tried to consistently indicate). Results should be interpreted cautiously, in view of the measurement and structural uncertainties.

Exploring the structural uncertainties in current knowledge was one of the key objectives of this paper. Implementing the available knowledge in the form of an agent-based model requires making ideas and linkages explicit. It helps formalise, structure, and integrate current understanding of Antarctic tourism-related challenges and identify emerging trends. The model's strength is not that any of the modelled events will occur; instead, it explores possible consequences of self-regulation challenges. The model's flexibility helped analyse concepts and individually test what factors resulted in changing patterns. Scenarios can be tested multiple times with slightly different input values to determine the results' robustness (this study repeated each variable 40 times). The presented results are only a few of the scenarios that can be explored with the model.

Despite all simplifications and uncertainties, lessons can be learned. The approach helps us understand the limitations to self-regulation of sustainable tourism, as well as underlying processes. The ABM scenarios show that small changes can have a big impact on sim-IAATO's ability to self-regulate and that not all developments are easily predicted (e.g. nonlinearities and tipping points). The results confirm previous studies' findings that commitment of voluntary members is a potential issue (e.g. Amelung & Lamers, 2006; Enzenbacher, 2007; Haase et al., 2009). However, how negative trends emerge depends on different factors. Some scenarios (e.g. growth of one operator type) follow an almost linear path. Other scenarios (e.g. membership cost, optimal group size, group effect on commitment, accidents) follow less predictable paths and have tipping points. Accident scenarios support several studies' conclusions (e.g. Amelung & Lamers, 2006; Enzenbacher, 2007; Liggett et al., 2011) that accidents and their impacts are highly uncertain and far-reaching. Similar to Bauer's study (1994), this study enables researchers and decision-makers to investigate a range of scenarios and include or ignore factors, such as accidents, that add further complexity to the system. This exercise makes emerging trends more tangible to researchers and operators while providing policy-makers with a stronger basis for developing policy for sustainable Antarctic tourism. For example, based on this study, we would urge decision-makers in industry and government to take a careful and adaptive approach to those factors that follow nonlinear paths.

The limitations found in the current model highlight questions that can and should be further explored. The model has exposed critical gaps in knowledge, such as on the existence and strength of a group size effect in the self-regulatory regime, as well as on the perceived relative costs and benefits of membership among various kinds of operators (see also Haase et al., 2009). As a better understanding emerges of how these mechanisms operate and interact, new insights can be added to the conceptual framework.

Our attempt to make the working of the self-regulatory system in Antarctica explicit from the viewpoint of individual tour operators makes it vulnerable to criticism. Important factors and relationships may not have been included. At the same time, this is also a major strength of the approach.

The model creates a platform for debate on how representative the model is and how insights can be used to inform policy-making or further research. Some contentious issues remain, such as space used and access. To address these, future models could focus more on the spatial dynamics (see also Lynch et al., 2010). Moreover, the results assess membership coverage, but if other factors influence IAATO's ability to self-regulate, those outputs can also be explored (e.g. membership coverage of yachts or other operator types).

A final avenue for further research may be linked to the nature of the challenges. Our model was limited to internal challenges: developments that are directly related to the tourism industry. External challenges may, however, also be highly relevant. For example, the ATS might decide to strengthen its grip on tourism regulation for reasons beyond the control of the tourism industry (see also Haase et al., 2009). Future studies may broaden the exploratory scope to include this kind of critical factors for tourism regulation in the Antarctic.

Conclusion

This study offers a new approach to identifying the main challenges affecting IAATO's ability to self-regulate sustainable Antarctic tourism. However, the approach provides more than an analysis of current understanding of Antarctic tourism.

This study explores complexity by systematically structuring the problem. Structuring and using different modelling techniques illustrates and possibly quantifies major uncertainties. Moreover, the documented and analysed assumptions using ABM improve theory. Studies mention that group effect on commitment is an issue (Haase et al., 2009; Landau & Splettstoesser, 2007b; Olson, 1965; Ostrom, 2005). However, the literature remains unclear how this mechanism works or whether commitment is negatively affected by group growth more than by the positive forces of increased experience. As a result of using different mechanisms, the model indicates that in some cases growth will negatively affect membership and in other cases have a negligible effect on membership. This demonstrates ABM's power to analyse uncertainties.

Moreover, the approach has application in policy. The results support claims that IAATO may lose the ability to represent the majority of operators. The model's findings indicate that two internal challenges dominate: membership cost and the group effect (i.e. how commitment is affected by membership). IAATO needs to understand how members perceive membership costs and make sure the costs are proportional to benefits members can access. Also, the model's outputs illustrate that having a larger membership may lie generally beyond IAATO's capacity to self-regulate (e.g. growth and diversity scenarios). Thus, IAATO must prepare to respond to a larger membership group and develop strategies to keep member engagement high so that members maintain their commitment level. Externally, ATCPs can provide IAATO with support for problems such as operator growth. First, ATCPs can make membership mandatory for obtaining permits or prohibit non-members from entering Antarctica (United Kingdom, 2004). Second, ATCPs can give IAATO the authority to ensure that guidelines are met. Accidents, even in low-risk scenarios, and other nonlinear trends may pose a real challenge for IAATO. In preparing for such conditions, both IAATO and ATCPs should apply Bastmeijer and Roura's (2004) recommendation of the precautionary principle (i.e. extra caution when uncertain) for considering adaptive policy.

This research advances the field by enabling a safe form of experimenting in Antarctic governance (i.e. computer-based instead of field-based). The process and the results enable researchers and decision-makers to analyse self-regulation challenges and uncertainties. This analysis provides decision-makers guidelines for addressing uncertainty and developing strategic policy to ensure sustainable Antarctic tourism.

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No potential conflict of interest was reported by the authors.

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