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Review

Evaluation of non-native species policy development and implementation within the Antarctic Treaty area

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ABSTRACT

Antarctic non-native species legislation is contained within the Protocol on Environmental Protection to the Antarctic Treaty, with 2016 marking the 25th anniversary of its adoption. We take this opportunity to evaluate the Antarctic Treaty signatory Parties' collective development and implementation of non-native species policy. In general, scientific and policy outputs have increased in the past decade. However, data detailing Parties' current implementation of biosecurity practices are not readily available. Little widespread, internationally coordinated or systematic monitoring of non-native species establishment has occurred, but available data suggest that establishment of non-native micro-invertebrates may be greatly underestimated. Several recent small-scale plant eradications have been successful, although larger-scale eradications present a greater challenge due to seed bank formation. Invertebrate establishment within research station buildings presents an increasing problem, with mixed eradication success to date. The opportunity now exists to build on earlier successes, such as the 'CEP Non-native Species Manual', towards the development of a comprehensive response strategy based upon the principles of prevention, monitoring and response, and applicable to all Antarctic environments. To help facilitate this we identify areas requiring further research and policy development, such as to reduce anthropogenic transfer of indigenous Antarctic species between distinct biogeographic regions, avoid microbial contamination of pristine areas and limit introduction of non-native marine species. A response protocol is proposed for use following the discovery of a potential non-native species within the Antarctica Treaty area, which includes recommendations concerning Parties' initial response and any subsequent eradication or control measures.

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1. Introduction

Antarctica is one of the last regions of Earth to remain largely unimpacted by invasive non-native species; however, the number of known introductions is increasing and may present one of the greatest threats to Antarctic biodiversity (Frenot et al., 2005; Hughes et al., 2015a). Legislation concerning non-native species introductions to the Antarctic Treaty area (the area south of latitude 60ºS) is contained predominantly within the Protocol on Environmental Protection to the Antarctic Treaty (adopted 1991, entered into force 1998). Under the auspices of the Antarctic Treaty (adopted in 1959, entered into force in 1961) the 29 Consultative Parties represented at the annual Antarctic Treaty Consultative Meeting (ATCM) comprise the body responsible for the governance of the Antarctic Treaty area. Several authors have suggested that the ATCM and wider Antarctic Treaty System may not be adequately responsive to emerging conservation challenges, but is this the case for non-native species issues (Chown et al., 2012a; Convey et al., 2012; Hughes et al., 2014; Tin et al., 2014)? Following a recent analysis of the state of non-native species management in the broader Antarctic region (McGeoch et al., 2015), we evaluate non-native species policy development and implementation within the Antarctic Treaty area by signatory Parties. The 25th anniversary of the Protocol's adoption will be celebrated in 2016 and we hope this review will inform future targeting of scientific research, policy development and environmental management practices by Treaty Parties.

2. Methods

Quantification of academic papers concerning non-native species in Antarctica was achieved using Thomson Reuters 'Web of Science' and the search terms 'non-indigenous', 'non-native', 'Antarct*' and 'alien'. Academic papers described within policy papers submitted to the Committee for Environmental Protection (CEP) were also included. Policy papers submitted to the ATCM and CEP were accessed from the Antarctic Treaty Secretariat website at: http://www.ats.aq/index_e.htm. Data on non-native species eradications and management were taken from the literature and relevant policy papers submitted by CEP Members and Observers.

3. Antarctic ecosystems

Antarctic terrestrial habitats are isolated and limited as ice-free ground comprises only 0.34% of the continent's vast 14 000 000 km^2 area, predominantly as nunataks and seasonally snow-free ground (Convey, 2007) (Fig. 1). Most visible biota is found along the coast, particularly along the Antarctic Peninsula and nearby archipelagos and the 'oases' of the East Antarctic, while the McMurdo Dry Valleys (southern Victoria Land), provide the only example of an extensive ice-free area (Levy, 2013). Antarctic terrestrial biodiversity and species richness is low with terrestrial fauna largely restricted to micro-invertebrates and two insect species, while the flora is limited to cryptogams with only two native higher plants (Smith, 1984). With increasing distance from the coast and higher altitude, macroscopic biodiversity declines and microorganisms (e.g. bacteria, fungi and algae) dominate at in-land sites. In contrast, large sea bird and marine mammal populations breed on the coast, and marine ecosystems are biologically diverse and rich, with high species-level endemism (Aronson et al., 2011; De Broyer et al., 2014). Increasing tourism industry and national operator activity, coupled with climate change and pollution from sources outside of the region, mean Antarctic ecosystems are under mounting threat, not least from non-native species (Frenot et al., 2005; Bargagli, 2008, Tin et al., 2009). The extent of non-native species in the marine realm is largely unknown; hence, in this work we focus predominantly on Antarctic terrestrial communities.

4. Non-native species legislation

The Antarctic Treaty System is the agreed legislative framework for the region (Berkman et al., 2011). Despite almost all nations active in Antarctica being signatories to the Convention on Biological Diversity (CBD), the Convention and any associated targets do not apply to the Treaty area. Alongside the Treaty itself, which says little about Antarctic conservation, the Protocol on Environmental Protection to the Antarctic Treaty (entered into force 1998) is the instrument concerned with general Antarctic protection and conservation, while the Convention on Conservation of Antarctic Marine Living Resources (CCAMLR; entered into force 1982) is concerned with the conservation of Antarctic marine life and regulates marine species harvesting. The Protocol designates Antarctica as a continent for '*peace and science*', sets out legislation for its protection and conservation through a series of Annexes and established the Committee for Environmental Protection (CEP) to provide advice to the ATCM on environmental issues. Mindful of the region's pristine nature, the low level of species introductions and its importance for scientific research, those drafting the Protocol set some of the highest legislative standards found globally concerning non-native species (see Fig. 2). Amongst other things, the Protocol states that dogs (used for sledge-pulling) are to be removed, non-native plants and animals shall not be introduced to Antarctica (with the exception of imported foods) and that any species found shall be removed or disposed of unless it is shown that they pose no risk to native biota (albeit, this is difficult to prove conclusively) (Hughes and Convey, 2010, 2014; Hughes et al., 2015a). This contrasts with the goals set out in Aichi Biodiversity Target 9 of the Convention on Biological Diversity (CBD) Strategic Plan for Biodiversity 2011–2020, i.e. that by 2020 invasive alien species and pathways are identified and prioritized, priority species controlled or eradicated and measures are in place to manage pathways to prevent their introduction and establishment (UNEP, 2010; for wider discussion see Chown et al., 2015). Most elements of Target 9 are less stringent that the Protocol, due in large part to the nature and extent of the invasive species problem across the globe compared to Antarctica, and concern predominantly invasive species rather than all non-native species.

5. Non-native species policy development and implementation

Recognizing the challenges associated with implementation of the legislation set out in the Protocol concerning non-native species, and noting scientific publications outlining the extent and risks of non-native species to Antarctic ecosystems (e.g. Frenot et al., 2005), New Zealand hosted a 'Non-native Species Workshop' in Christchurch in 2006. The workshop provided an opportunity for scientists, environmental managers and policy experts to discuss how the emerging threat could be addressed (Rogan-Finnemore, 2008). Submission of the workshop report (New Zealand, 2006) to the CEP at ATCM XXIX (Edinburgh, June 2006) resulted in non-native species issues being assigned the highest priority within the CEP work plan. At the same time non-native species research was being planned by scientist from several countries, including as part of the International Polar Year (IPY) 2007/09 'Aliens in Antarctica' project, resulting in higher numbers of relevant academic publications in the following

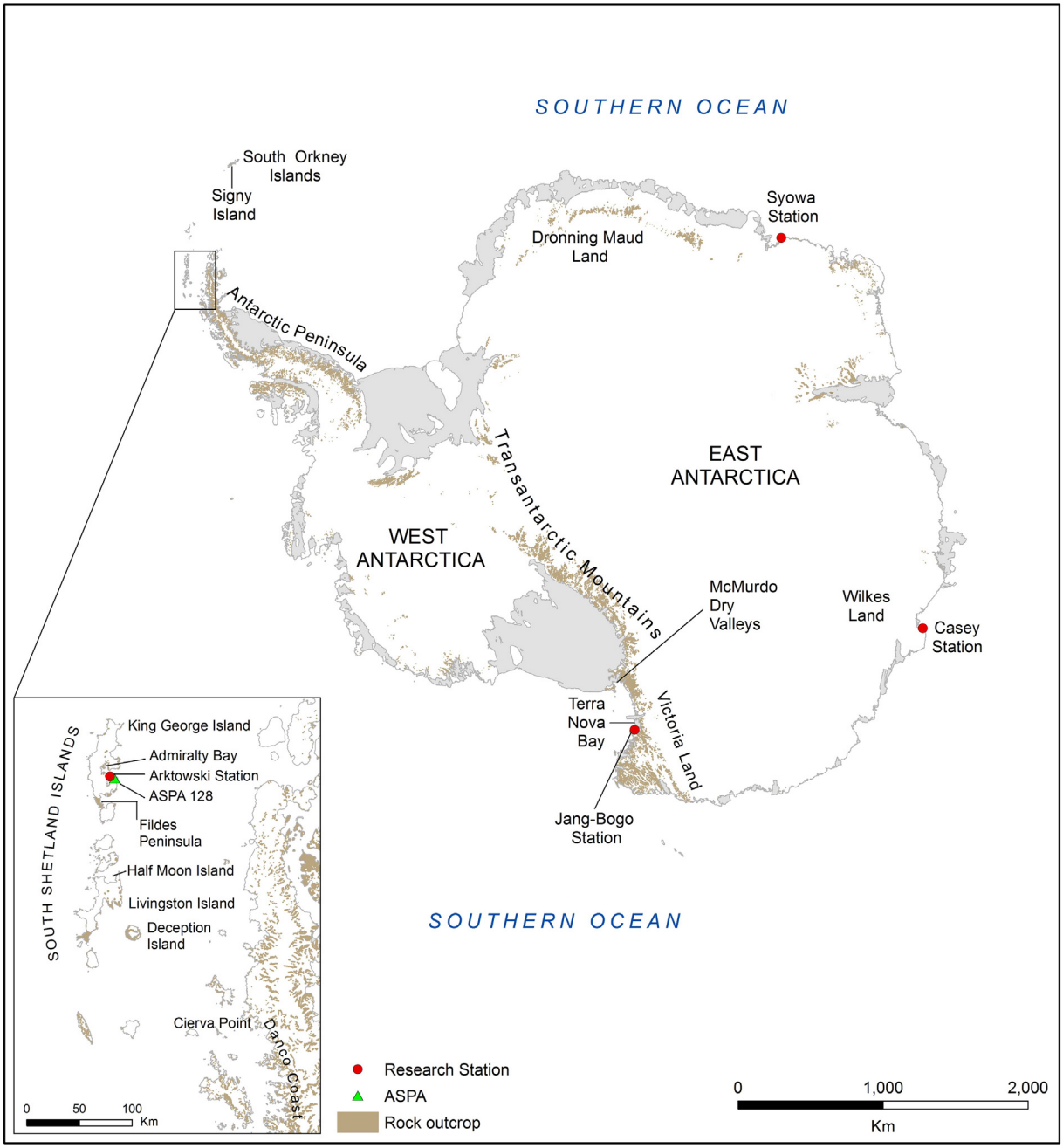

Fig. 1. Map of the Antarctic Treaty area showing locations mentioned in this paper.

years (see Fig. 3) (Chown et al., 2012b; Huiskes et al., 2014). In 2011 the Committee produced non-compulsory guidance on managing non-native species in the form of the CEP Non-native Species Manual (Edition 2011) (CEP, 2011; available at: http://www.ats.aq/documents/atcm34/ww/atcm34_ww004_e.pdf), which was agreed at ATCM XXXIV (Buenos Aires, June, 2011) through Resolution 6 (2011). The agreement of the Manual by all (as then) 28 Consultative Parties to the Antarctic Treaty was a considerable success, and raised awareness of non-native species issues across the Antarctic community, while, at the same time, provided useful information for Antarctic operators. The Manual set out a recommended framework for Party management action under the headings 'Prevention', 'Monitoring' and 'Response'. Including the headings set out in the CEP Manual, we evaluate the development of non-native species management practices in Antarctica.

5.1. Prevention

Supported by research quantifying non-native species propagule transfer to Antarctica in association with personal clothing, equipment, cargo, vehicles and fresh foods (Whinam et al., 2005; Lee and Chown, 2009a; Hughes et al., 2010, 2011; Chown et al., 2012b; Huiskes et al., 2014), the CEP Manual recognizes prevention of non-native species transfer to Antarctica as the most effective means of minimizing the associated risks. To support Parties in identifying simple cost-effective biosecurity measures to reduce propagule transfer, the Council of Managers of National Antarctic Programs (COMNAP), in association with the Scientific Committee on Antarctic Research (SCAR), produced the '*Checklist for supply chain managers of national Antarctic programs to reduce the risk of transfer of non-native species*' (available at: https://www.comnap.aq/Publications/Comnap%20Publications/COMNAP_SCAR_

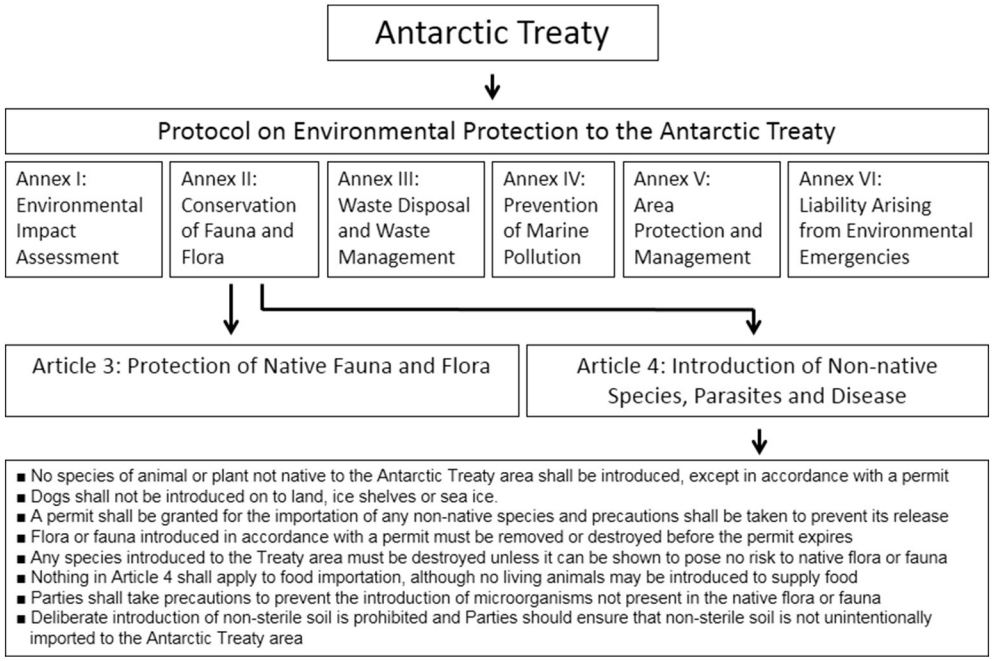

Fig. 2. Legislative framework concerning non-native species within the Antarctic Treaty area.

Checklists_for_Supply_Chain_Managers.pdf). Like the CEP Non-native Species Manual, this checklist was influential in raising the profile of non-native species issues and highlighted that relatively inexpensive measures could be taken to minimize the risks of non-native species introductions to Antarctica. However, despite initial high profile policy successes, it is difficult to ascertain the levels of implementation of these and other biosecurity guidelines. Some Parties have demonstrated commitment to the implementation of biosecurity measures with the construction of new facilities (Australia, 2013), development of national operator-specific guidelines and protocols (Australia and France, 2012; Houghton et al., 2016; Hughes, 2015), production of educational materials (COMNAP, 2015) and information resources such as the Alien Species Database (Australia and SCAR, 2011). Basic biosecurity measures have been developed for some protected areas, e.g. Antarctic Specially Managed Area (ASMA) 4 Deception Island and ASMA 6 Larsemann Hills. The last broad assessment of biosecurity practice by Parties was undertaken by COMNAP in 2008. This revealed great variation in the level of effort assigned to biosecurity issues by national operators. Notably, only 9% of the survey respondents implemented quarantine-type procedures involving isolation of certain items before transit to Antarctica (COMNAP, 2008). In contrast, the Antarctic tourism industry, through the International Association of Antarctica Tour Operators (IAATO), has been proactive in implementing biosecurity practices for tourists and staff going ashore from its members' vessels and at in-land sites (IAATO, 2015).

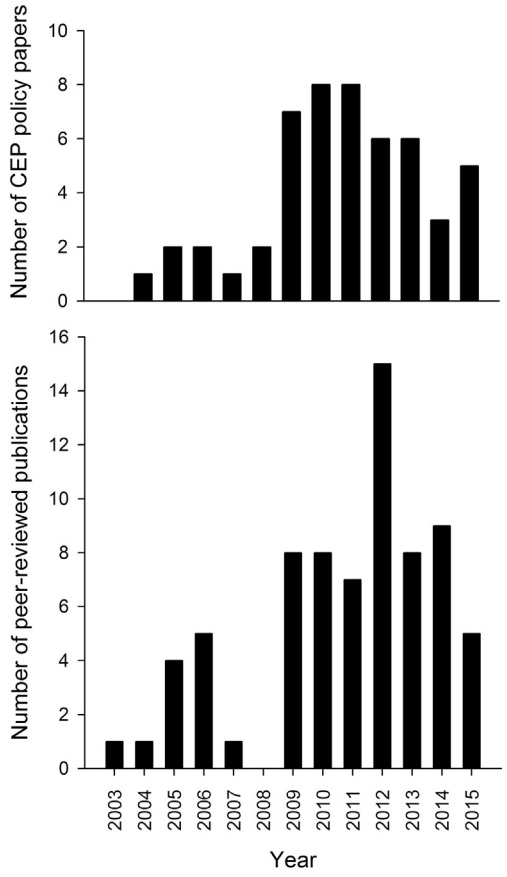

Fig. 3. Policy papers relevant to non-native species issues submitted to the Committee for Environmental Protection (CEP) and peer-reviewed publications on Antarctic non-native species generated between Jan 2003 and November 2015.

Procedures have yet to be developed by the CEP to reduce specifically the risk of indigenous species transfer between biogeographic regions in Antarctica (Antarctic Conservation Biogeographic Regions, as defined by Terauds et al., 2012) in order to prevent biological homogenization of the continent's regionally distinct biota. Marine introductions have received some consideration by the CEP. Ballast water management guidelines were agreed in 2006 and later adopted by the International Maritime Organization's (IMO) Marine Environment Protection Committee (MEPC) (Resolution MEPC.163(56); July 2007). Since that time progress has slowed, particularly with regard to practical management of hull fouling communities (Lewis et al., 2003; Lee and Chown, 2009b; Hughes and Ashton, 2016).

5.2. Monitoring and surveillance

Regular monitoring of high-risk sites is encouraged in the CEP Non-native Species Manual and may be particularly important around visitor sites (see: http://www.ats.aq/e/ats_other_siteguidelines.htm) and

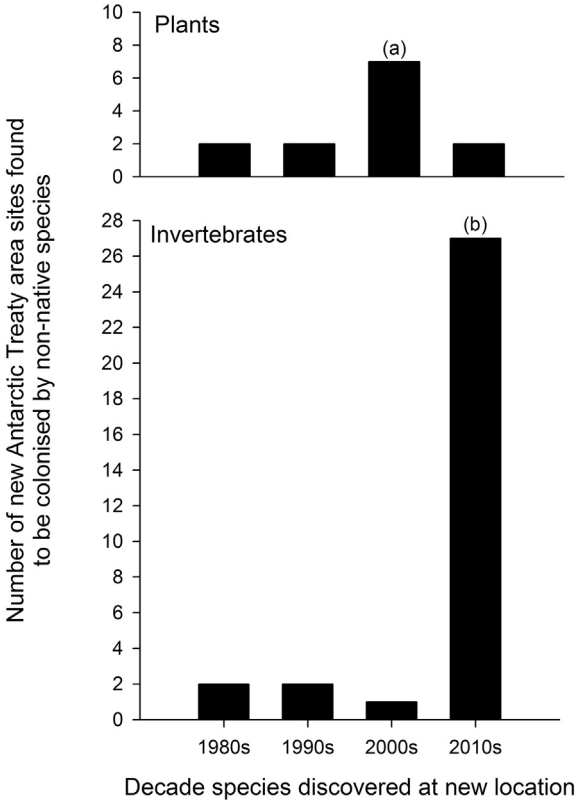

Fig. 4. Number of new Antarctic Treaty area sites found to be colonized by non-native species each decade between 1980 and 2015. (a) Four of the plants identified in the 2000s were found following targeted monitoring by Molina-Montenegro et al. (2012). (b) Twenty five of the invertebrates identified since 2010 were discovered as a result of targeted monitoring by Greenslade et al. (2012) and Russell et al. (2013).

research stations. However, information on non-native species monitoring by Parties is not readily available, although some scientific reports of targeted monitoring activities do exist (Fig. 4). Molina-Montenegro et al. (2012) monitored 25 sites on the Antarctic Peninsula and offshore islands and found the non-native grass, *Poa annua*, at six locations (24%). Russell et al. (2013) undertook a comprehensive examination of cryptic non-native soil fauna in 13 areas of high visitation by tourists and national operator staff, also in the Peninsula region (Germany, 2013). The study found at least one of eight non-native species (Collembola and Actinedida) across 11 of these locations (85%), with the highest species number recorded from Deception Island, South Shetland Islands (Russell et al., 2013). Greenslade et al. (2012) identified a widespread distribution of non-native species during similar studies focused on Deception Island. Together, these data suggest that non-native species are often present at highly visited locations, particularly in the climatically less extreme Peninsula region of Antarctica. Given the large number of locations where monitoring has not occurred, it is likely that the known extent of non-native introductions, and especially micro-invertebrates, is greatly underestimated.

Detecting and identifying non-native species, and soil microfauna in particular, requires appropriate taxonomic expertise that is increasingly difficult to acquire. Recognizing this challenge, the Republic of Korea introduced a meta-barcoding approach with high-throughput sequencing technology to deliver rapidly information on the diversity and local distribution of meiofauna around Jang-Bogo Station, Terra Nova Bay, Victoria Land (Republic of Korea, 2015; see also Chown et al., 2008). Wider implementation of such technologies may revolutionize non-native species surveillance and monitoring; however, species identity verification will still depend to some degree upon traditional taxonomic expertise.

As far as we are aware, targeted monitoring of marine environments for non-native species has received little or no specific attention.

5.3. Response

The CEP Non-native Species Manual emphasizes that a quick response that assesses the feasibility and desirability of eradicating a non-native species is a key factor in successful management. Furthermore, it states that '*to be effective*, *responses to introductions should be undertaken as a priority*, *to prevent an increase in species*' *distribution range and to make eradication simpler*, *cost effective and more likely to succeed*' and encourages follow up surveys to ensure management action is effective. However, formal agreement on what constitutes a rapid response has yet to be reached. As an example of standards set in other parts of the world, within the context of the European Union, Article 17 '*Rapid eradication at an early stage of invasion*' contained within '*Regulation (EU) No. 1143/2014 of the European Parliament and of the Council of 22 October 2014 on the prevention and management of the introduction and spread of invasive alien species*' states that States shall apply eradication measures within three months of detection (see: http://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1417443504720&uri=CELEX:32014R1143). Seasonal and logistical factors may make this three month period inappropriate for application within the Treaty area, but it does provide a bench-mark to which Treaty Parties could aspire.

Fig. 5 shows the number of successful eradications within the Antarctic Treaty area per decade over the past 35 years (based on data shown in Table A1 (supplementary data) that lists the non-native plants found within the Antarctic Treaty area and any subsequent management action). Management responses have varied depending upon the circumstances, but in general, efforts in the past five to ten years have seen all recent and historic non-native plant introductions eradicated or management activity initiated. This notable success could be seen as a direct result of earlier scientific and policy work that raised the profile of non-native species issues within the Parties. In stark contrast, however, no attempts have been made to eradicate non-native invertebrates in the Antarctic terrestrial environment, possibly due to a lack of reliable eradication methods for this biological group (Hughes et al., 2015a).

5.3.1. Naturalized species: long-term introductions with little or no management

Within the Antarctic Treaty area, no non-native plant species has, as yet, become fully naturalized. However, *P. annua* has been introduced on multiple occasions (Chwedorzewska, 2008; Chwedorzewska and Bednarek, 2012; Molina-Montenegro et al., 2012) and it is not known how feasible it will be to eradicate *P. annua* at Admiralty Bay, King George Island, South Shetland Islands, before it disperses further (Fig. 6). Control or eradication of introduced invertebrates has received little attention in the Antarctic Treaty area (see Table 5 in Hughes and Convey, 2012). Introduced invertebrates have belonged typically to groups such as Acari, Collembola or Diptera, with some species becoming increasingly widespread (e.g. *Hypogastrura viatica*; Fig. 6) (Hughes et al., 2015a). Limited to methodologies conforming to existing Antarctic legislation (i.e. the general prohibition of pesticide use), little cost-effective eradication management can be done once cryptic species become established over anything other than the smallest areas (Hughes et al., 2015a). However, eradications of synanthropic species have been attempted with varied success (Hughes et al., 2005; Houghton et al., 2016; Volonterio et al., 2013). Due to the difficulty of introduced invertebrate eradiation and the ease of human-mediated dispersal, some species may become naturalized, of which a subset may present a substantial threat to Antarctic biodiversity and ecosystem structure and function (Mack et al., 2000). Biosecurity measures to prevent indigenous and non-native species transfer between locations within Antarctica are employed by some elements of the tourism industry

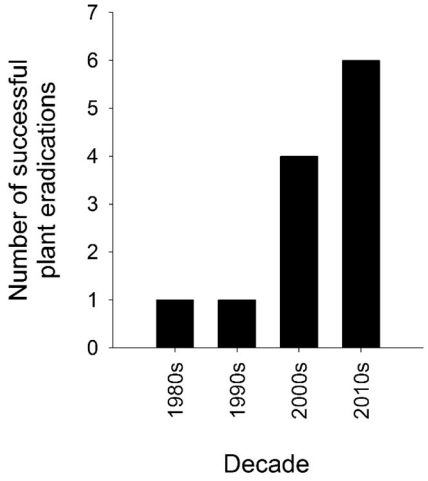

Fig. 5. Number of successful non-native plant eradications per decade since 1980.

and some national operators, but evidence demonstrating widespread implementation has yet to be produced (IAATO, 2015; Hughes, 2015).

5.3.2. Delayed non-native plant management: a thing of the past?

Earlier introductions of non-native species in Antarctica have been subject to delayed management action due to a lack of awareness of the risks or consensus on the most appropriate management response. The human-mediated introduction of *P. annua* to Admiralty Bay during the 1985/86 austral summer season (and five years prior to the adoption of the Protocol) generated differences of opinion on the value of maintaining the introduced species for scientific research purposes compared to the impacts on Antarctic conservation (Smith, 2011; Fig. 6). Environmental management action gave way to scientific research into the potential naturalization process of the species (Olech, 2003). During the 2014–15 season, *P. annua* in Admiralty Bay was subjected to active management by the Polish national program with partial eradication of the grass (Poland, 2015), but it remains to be seen if full eradication is possible, particularly due to the seed bank present in the soil (Molina-Montenegro et al., 2012, 2014, 2015; Wódkiewicz et al., 2013).

Delayed management activity may also be due to lack of awareness of the introduction or no one Party taking responsibility to lead the management work. For example, *Poa pratensis* established at Cierva Point, Danco Coast, Antarctica Peninsula, in 1954/55 was reported in the scientific literature on at least in two occasions (Corte, 1961, Smith, 1996) but no specific investigation to ascertain the plant's colonization status was undertaken until visited by Spanish researchers in 2012. *P. pratensis* had persisted and spread beyond its earlier extent, yet was not able to reproduce sexually, which may have limited its dispersal potential (Pertierra et al., 2013). Subsequently, policy papers, co-sponsored by three Parties, were presented to the CEP describing the species colonization status (Spain et al, 2012), plans for its management (Argentina et al., 2013) and its successful removal (Argentina et al., 2015). The process took over three years to complete, demonstrating that the mechanisms of international diplomacy may make a rapid response difficult to achieve (Fig. 6; Table 1). Nevertheless, these examples suggest that some Parties are beginning to prioritize eradication and control of long-term non-native plant colonists near their research stations.

In the past decade a more 'rapid response' to non-native plant introductions, as advocated within the CEP Non-native Species Manual, has become increasingly common within the Antarctic Treaty area, potentially signaling a realization that prompt action is likely to be more successful and cost-effective (Fig. 5; Table 1). Most attempted eradications have involved individual or small numbers of plants located in discrete areas, e.g. *Puccinella svalbardensis* near Syowa Station, Dronning Maud Land (Japan, 1996; Hughes and Convey, 2010; Tsujimoto et al., 2010), *Nassauvia magellanica* on Deception Island, (United Kingdom and Spain, 2010; Smith and Richardson, 2011; Hughes and Convey, 2012) and *P. annua* at Deception Island and three research stations on the northern Antarctic Peninsula (Molina-Montenegro et al., 2012) (see Figs. 5, 7 and Table 1). As a result, almost all known historically introduced vascular plants in Antarctica have been removed, with only *P. annua* at Admiralty Bay remaining (Hughes et al., 2015a; Poland, 2015) (Table A1 — supplementary data). Nevertheless, new plants may reappear from seed banks or be reintroduced, as occurred in Paradise Bay in 2013 after the removal of *P. annua* in 2009/10 (Molina-Montenegro et al., 2015) indicating the need for on-going surveillance.

5.3.3. Long-term management and control

Non-native species eradication may often not be a feasible option, due to a lack of effective eradication methodologies, the scale of eradication impacts on indigenous species and Antarctic habitat or the Parties' interpretations of the Protocol itself (see Hughes et al., 2015a). In such cases, on-going management and control of non-native species may be the only option other than doing nothing. For example, the flightless chironomid midge, *Eretmoptera murphyi*, was introduced to Signy Island, South Orkney Islands, from sub-Antarctic South Georgia, probably in the late 1960s, but due to the extent and nature of the area colonized, eradication was deemed unlikely to succeed (Hughes and Worland, 2010). As the most cost-effective and least environmentally destructive option, strict biosecurity measures have been put in place on the island by the British Antarctic Survey (BAS) to prevent further distribution of the midge (Hughes et al., 2013) (Fig. 6).

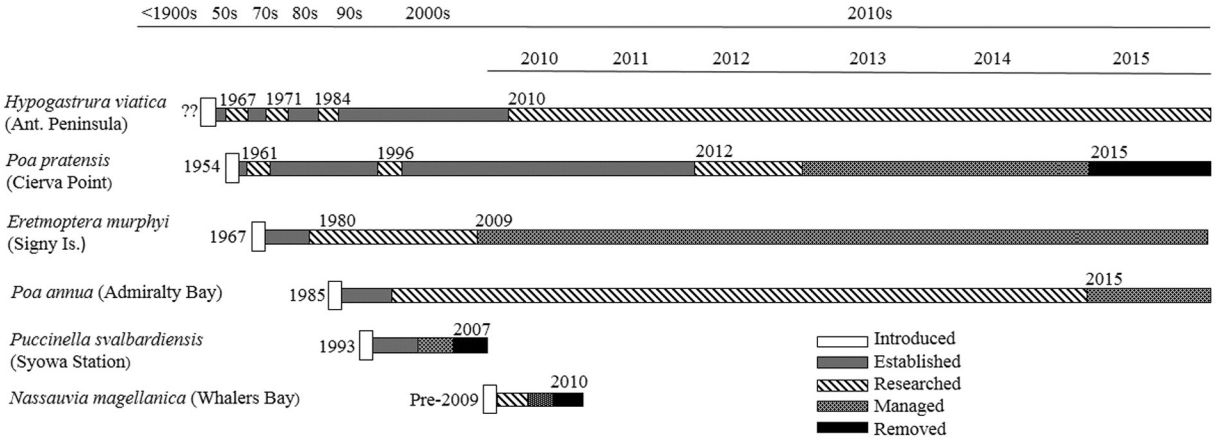

Fig. 6. Discovery, research and management of selected non-native species within the Antarctic Treaty area.

Table 1
Effort involved in non-native species management within the Antarctic Treaty area.

	Extent of colonization	Examples	Removal effort	Amount of soil, plant and root material removed	On-going monitoring effort required	References
1	Single plant or small number of plants	*Nassauvia magellanica*, Whalers Bay, *Poa annua* at General Bernardo O'Higgins station, Trinity Peninsula *Puccinellia sp.* near Syowa Station	1 person 1 h	<10 kg	Low-effort monitoring over a small area in the vicinity of the potential plant propagule source	Hughes and Convey (2012) Molina-Montenegro et al. (2012) Hughes and Convey (2010)
2	Patch of long-established turf (c. 1 m^2)	*Poa pratensis* at Cierva Point	3 people 3 days	c. 700 kg	Low-effort monitoring over a small area in the vicinity of the potential plant propagule source	Pertierra et al. (2013) Argentina et al. (2015)
3	Many plants over a large area (>100 m^2)	*Poa annua* around Admiralty Bay	Many people Many seasons	Likely to be several tons over many years, or herbicide use may be a more practical option	Extensive on-going monitoring over a wide area for new plants due to established seed bank	Poland (2015)
4	Extensive colonization area	The flightless chironomid midge, *Eretmoptera murphyi*, on Signy Island, South Orkney Islands	Removal would cause damage to an extensive area of habitat and, given the life history of the midge, the likelihood of success would probably be low	Impractical to remove soil. Chemical methods might be effective, but would result in extensive damage to existing habitat and indigenous species	Monitoring may be required to assess species expansion. Biosecurity measures are in place to ensure species remains confined to the island	Hughes and Worland (2010) Hughes et al. (2013)

Monitoring the distribution of known non-native species is essential to show the effectiveness of applied control measures, but also highlight the benefits of an early response compared to eradication or control once the species has expanded. Monitoring of *E. murphyi* on Signy Island showed that the area of ground colonized expanded from c. 1 m^2 in 1981 to >35 000 m^2 in 2009 (Hughes and Worland, 2010). *P. annua* at Arctowski Station, Admiralty Bay, expanded from single plants by the station entrance in the mid-1980s, to colonize 100 m^2 of ground over 1.5 km away within an adjacent protected areas (Antarctic Specially Protected Area (ASPA) No. 128 Western Shore of Admiralty Bay) in the 2008/9 season (Olech and Chwedorzewska, 2011) and then at a second site in 2014/15 (Poland, 2015). As yet, no detailed biosecurity measures relating to this introduction have been incorporated into the ASMA management plan that encompasses the colonized areas and adjacent stations.

Non-native species colonization of station buildings and sewage treatment facilities may also cause on-going management problems should earlier eradication attempts fail. For example, the dipteran *Lycoriella ingenue* has persisted synanthropically at Casey Station, Wilkes Land, for 18 years, despite costly eradication attempts (Hughes et al., 2005; Houghton et al., 2016). Similarly, attempts to eradicate the Holarctic Dipteran *Trichocera maculipennis* found in the sewage treatment plants at the Uruguayan station on Fildes Peninsula, King George Island, South Shetland Islands (2007–08) and the nearby Korean King Sejong station, Barton Peninsula (2013–14), were unsuccessful (Volonterio et al., 2013; J. Hee, pers. Comm.). *T. maculipennis* may have recolonized the station from individuals persisting in the natural environment and may also have colonized other stations in the local vicinity (Hughes et al., 2015a). Parties with hydroponic facilities have also reported finding introduced species, necessitating thorough cleaning of the facility in accordance with existing guidelines (Australia and France, 2012).

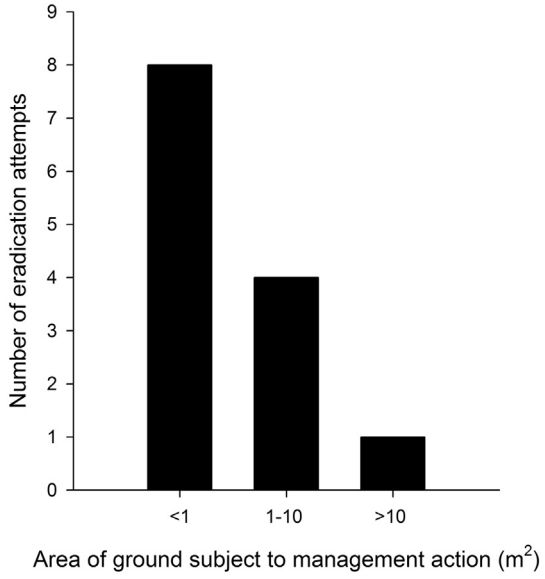

Fig. 7. Number of non-native plant eradication attempts over different areas of colonized ground since 1980. The eradication of *Poa annua* over an area >10 m^2 at Admiralty Bay, King George Island, South Shetland Island, is on-going (Poland, 2015).

Controlling non-native marine introductions is extremely difficult, and this would be particularly true under polar conditions. To our knowledge, no monitoring or control of Antarctic marine introductions (such as *Enteromorpha intestinalis* at Half Moon Island and Deception Island) has occurred (Clayton et al., 1997; Frenot et al., 2005).

6. Pace and scope of policy development and implementation

Initiatives such as the CEP Non-native Species Manual, and the COMNAP/SCAR '*Checklist for supply chain managers of national Antarctic programs to reduce the risk of transfer of non-native species*' effectively raised the profile of non-native species issues within the Antarctic community. However, overall, the pace of policy and guideline development has been slow and attention distributed unequally across different non-native species management issues. For example, the 2010 Antarctic Treaty Meeting of Experts on '*Implications of Climate Change for Antarctic Management*' emphasized the importance of preventing introductions, identifying species and environments at risk and developing measures to manage the issue. However, five years later, the recommendation for the production of a non-native species 'Response Strategy' has only now been agreed in the CEP Climate Change Response Work Programme (CCRWP; available from http://www.ats.aq/documents/ATCM38/att/ATCM38_att073_e.doc) as a high priority action for the coming years (Norway and United Kingdom, 2015). Furthermore, recent research recommended that the CEP consider the establishment of an international, long-term soil biological monitoring program (Germany, 2013). However, following further CEP discussions, effective progress has yet to be made, despite the CEP advocating the development of surveillance approaches for non-native species in its CCRWP

(Norway and United Kingdom, 2015). McGeoch et al. (2015) assessed the status of biological invasions in the broader Antarctic and sub-Antarctic region as a basis for monitoring and management, through the development of an 'Antarctic Biological Invasions Indicator' (ABII). The CEP could apply this framework to measure progress in management of non-native species within the Treaty area (SCAR, 2015).

In June 2015 the CEP agreed to undertake a revision of the CEP Non-native Species Manual, in light of scientific and policy developments in the previous five years (United Kingdom et al., 2015). While scientific research output on non-native species has been substantial in recent years (see Fig. 3), its use to systematically inform policy development has been unfocused. Consequently, many of the work areas detailed in the CEP Non-native Species Manual Annex '*Guidelines and resources requiring further attention or development*' have yet to receive the attention of the CEP.

Policy and guidelines on non-native species are of little value unless they become part of the standard operating procedures of organizations present within the Treaty area. The implementation of non-native species policy at all stages of the supply chain, including at logistic headquarters located within sovereign states, at gateway ports and within Antarctica itself, is the responsibility of individual Parties. Strong leadership and on-going scrutiny may be required to ensure precautions addressing non-native species issues are prioritized above the many other calls on Antarctic operators' often increasingly scarce resources. It is hoped that as non-native species policy and guidelines become more comprehensive and Parties continue to raise the profile of these information sources with those under their jurisdiction, the breadth and level of implementation of practical steps to reduce the risk from non-native species by operators and the Antarctic tourism industry may increase, leading to a universal rise in standards.

7. Conclusions and recommendations

7.1. Evaluation conclusions

Here we present our conclusions and evaluations regarding Parties' progress in different areas of non-native species policy development and environmental management.

Prevention: While some Parties enforce high quarantine standards, information on current levels of biosecurity implementation and effectiveness across all Parties, operators and industries is not readily available. However, non-native species are still reported from stations and in the natural environment, indicating that further improvement is needed.

Monitoring: With some notable exceptions (Russell et al., 2013; Germany, 2013), most non-native species monitoring is opportunistic and science-led, as opposed to being commissioned with policy and management outcomes in mind. Based on the few published sources that exist, our understanding of the number and extent of non-native species introductions may be greatly underestimated, particularly regarding micro-invertebrates.

Response: In the past decade, Parties' responses to plant introductions have been increasingly rapid and effective. In the natural environment, acceptable methods either do not exist currently or have not been used to eradicate non-native invertebrates (particularly those with flying life-cycle stages). Synanthropic invertebrate eradications have succeeded on occasions, but winged species within sewage facilities have withstood eradiation attempts. With few exceptions, longer-term management and control of established non-native species has been minimal and little consideration has been given to the implementation of additional biosecurity at visitor sites colonized by non-native invertebrates on the Peninsula identified by earlier monitoring activities.

Policy development and implementation: Since the Protocol's adoption, in general, policy development has not been rapid, with influential successes (such as the CEP Non-native Species Manual) driven, predominantly, by interested individuals within the CEP and SCAR. As a consequence, policy on Antarctic non-native species management remains underdeveloped, largely hortatory and the effectiveness of its implementation by some Parties is unclear. Currently, no comprehensive internationally agreed response strategy exists, but progress in this area, should it occur, could constitute one of the CEP's most significant achievements on this issue to date.

7.2. Recommendations

To ensure Antarctica's continued status as free of widespread invasive species, the Treaty area should have the most stringent and best observed non-native species protocols and guidelines on Earth. Twenty-five years after the adoption of non-native species legislation in the Protocol on Environmental Protection to the Antarctic Treaty, our evaluation shows that while some progress has been made, gaps in research, policy development and implementation still remain. Consequently, we recommend that Antarctic scientists, policy makers, environmental managers and other stakeholders together focus on the following:

Prevention:

1. Research into anthropogenic and natural vectors of non-native species once within Antarctica, plus implementation of biosecurity measures to reduce further distribution of existing non-native species in Antarctica to other locations.
2. Research into the anthropogenic transfer of indigenous Antarctic species between the different Antarctic biogeographic regions (Terauds et al., 2012) and development of practical intra-regional biosecurity methods (Lee and Chown, 2011; Terauds et al., 2012).
3. Research on non-native marine species introduction risks, including development of practical methods to reduce introduction rates (Lewis et al., 2003; Lee and Chown, 2009b; Hughes and Ashton, 2016)
4. Research and continued policy development on prevention of non-native microbial introductions to pristine Antarctic sites (Cowan et al., 2011; Hughes et al., 2015b)

Monitoring:

5. Co-ordinated, frequent and widespread monitoring, using traditional and molecular methods, for non-native species at highly visited sites in both the marine and terrestrial environments (Lee and Hughes, 2010; Germany, 2013)

Response:

6. Development of appropriate contingency plans at sites identified as vulnerable to non-native species colonization (Jiménez-Valverde et al., 2011).
7. Research on methods to eradicate non-native invertebrates and micro-invertebrates (living both synanthropically and in the Antarctic environment) and to remove non-indigenous plant propagules within seed banks in Antarctica.

Policy development and implementation:

8. Regular evaluation of progress in non-native species policy development and management within the Antarctic Treaty area (see McGeoch et al., 2015; SCAR, 2015)
9. A regular review of biosecurity practices undertaken by all national operators (including military support), tourist and fishing organizations operating in Antarctic to provide an overview of biosecurity standards implemented across the continent and between biogeographic regions (e.g. COMNAP, 2008).

7.3. Response protocol

Despite existing non-native species legislation, some Parties may not see control and eradication of non-native species as a priority. Small scale responses have often been initiated opportunistically by individual

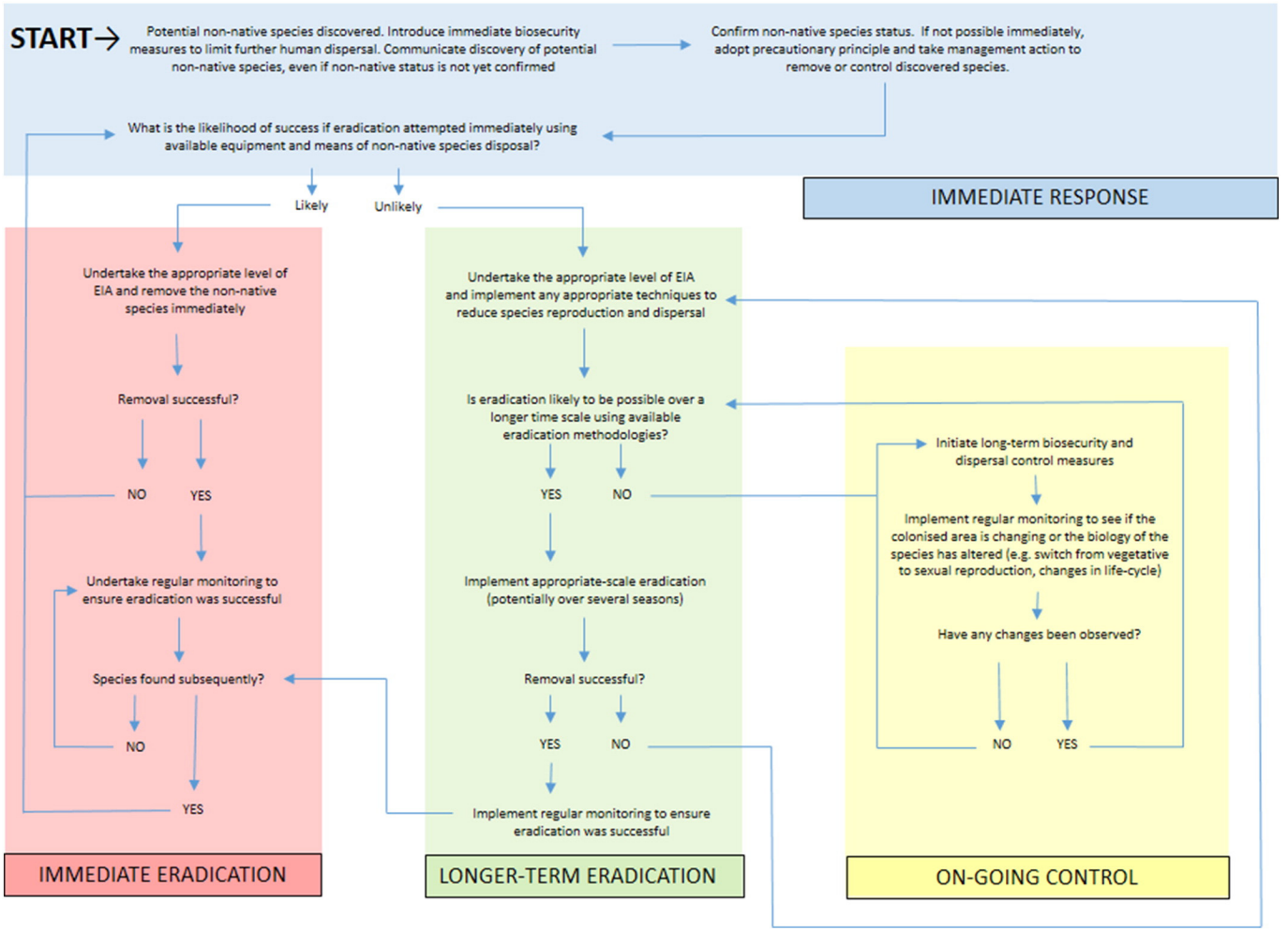

Fig. 8. Response protocol guidelines to be implemented upon the discovery of a potential non-native species inadvertently introduced to the Antarctic Treaty area. EIA: Environmental Impact Assessment. The protocol should be used in conjunction with Table A2 (supplementary information).

scientists. Where more complex eradication responses have been required, communication issues between stakeholders on planning and resourcing may have caused delays. This has led us to ask what system is best placed to expedite a rapid response, yet facilitate wider consultation to: (i) maximize management success, (ii) provide learning opportunities for other Parties who many encounter similar scenarios, and (iii) ensure CEP is aware of knowledge gaps, so future research and management efforts are targeted appropriately. We propose a response protocol (or contingency plan decision tree) for use following the discovery of any potential non-native species within Antarctica (see Fig. 8 and Table A2 — supplementary data); however, the details of any given situation may require specific consideration by appropriate experts. Together with the guidelines contained within the CEP Non-native Species Manual, this may promote development of a broader response strategy that is universally understood, agreed and applied by the Treaty Parties, national operators and tourism industry. Development and implementation of this strategy could silence any concerns regarding the ability of the ATCM and Antarctic Treaty System to manage non-native species issues and safeguard Antarctic biodiversity and ecosystems for the future.

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