Biological Conservation 238 (2019) 108236

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon

Cost-bene t based prioritisation of orangutan conservation actions in Indonesian Borneo

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ARTICLE INFO

Keywords:
Bornean orangutan
Cost-e ectiveness
Program evaluation
Project prioritisation

ABSTRACT

Each year an estimated US$20–30 million is spent by government and non-government organisations in e orts to conserve the Bornean orangutan. However, recent population analysis reveals that these e orts have been unable to reduce species decline. A major aim of the Indonesian National Action Plan for orangutan conservation is to "improve in-situ conservation as the principal activity ensuring the orangutan's survival in its native habitats". This paper summarises and examines current investment in conservation activities and provides recommendations on the strategic allocation of funds for future conservation. The cost data of major conservation initiatives, including orangutan rescue and rehabilitation, habitat protection, habitat restoration and community education, was collated from non-government agency annual reports and primary literature. A recent population density and distribution model, and reports documenting the e ectiveness of conservation strategies for the species were then used to calculate population trends in the presence and absence of interventions. Using an open-access cost-e ectiveness resource allocator tool, we investigate expenditure and program performance. We then provide recommendations on how to strategically allocate conservation funding to future programs to ensure maximum e ectiveness.

1. Introduction

Populations of the Bornean orangutan (*Pongo pygmaeus*) are rapidly declining. Over the past 20 years, populations are estimated to have decreased by 50%, representing > 100,000 individuals, primarily as a result of land clearing, hunting and human-wildlife con ict (Santika et al., 2017a; Voigt et al., 2018). Although legally protected in Indonesia since the 1920s, conservation e orts for the species gained international attention with the work of Barbara Harrison in the 1960s (Harrisson, 1961) and Birute Galdikas in the 1970s. Currently, over 61 non-government organisations (NGOs) are involved in conservation e orts for the species (Morgans et al., 2017) with the total (including government expenditure) annual investment during 2014 estimated to be US$20 million dollars (Meijaard, 2014). Despite the duration and magnitude of investment in the protection of orangutan, there is little evidence of positive outcomes on overall orangutan population trends. Poor environmental governance, coupled with a lack of coordination between conservation organisations, projects and other partners, explain the lack of real impact on the major threats that continue to a ect the species (Rijksen and Meijaard, 1999; Fisher, 2010; Meijaard et al., 2012; Morgans et al., 2017; Santika et al., 2017a; Voigt et al., 2018).

In 2007 the Indonesian Government presented the rst o cial Orangutan National Action Plan (NAP), which broadly aimed to "maintain populations and habitat in a stable condition" by 2017. This master plan had ve main objectives, the rst being primarily concerned with strategies and programs for the conservation management of orangutans through both in-situ habitat protection and management activities, alongside ex-situ care of orangutans in research facilities and zoos (Ministry of Forestry of the Republic of Indonesia, 2009, Section A). To date, the NAP has been unable to meet the key objectives outlined in the 2007 document (e.g. the closure of orangutan rescue centres by 2015 and stabilisation of wild populations by 2017). There is also little evidence to demonstrate the e ectiveness of the proposed strategies relative to their cost due to inadequate reporting of expenditure and evaluation of program performance (Meijaard et al., 2012; Wilson et al., 2014). Current population estimates predict a further 45,000 Bornean orangutans will die by 2050 (Voigt et al., 2018) unless conservation management improves signi cantly.

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https://doi.org/10.1016/j.biocon.2019.108236
Received 20 December 2018; Received in revised form 25 August 2019; Accepted 30 August 2019
0006-3207/

Although the need for targeted management interventions to address the drivers of orangutan population decline has long been established (Marshall et al., 2009; Meijaard et al., 2012; Wich et al., 2012; Santika et al., 2017a; Spehar et al., 2018), the recent upgrading of the Bornean species from Endangered to Critically Endangered on the IUCN Red List (Ancrenaz et al., 2016) presents a renewed sense of urgency for improved orangutan population management. At present, however, the Indonesian Government does not recognise this urgency and recently published a report claiming that orangutan populations had increased by at least 10% in the past three years based on a small subsample of populations found in protected areas, some of which are used for orangutan introductions and translocations (Ministry of Environment and Forestry, Republic of Indonesia, 2018). This lack of uptake of scienti c information for the purpose of informing policy, indicates a major disconnect between conservation science and political awareness (Meijaard et al., 2018). To build on the initial aims of the Indonesian NAP, this paper provides a summary of the major conservation actions being undertaken for the species including aims, accomplishments and challenges. Opportunities for future actions are then identi ed with the nancial costs calculated. In light of the 2016 orangutan population and habitat viability assessments, which examined key threats to orangutans and identi ed priority populations for conservation (Utami-Atmoko et al., 2017), we conducted a preliminary assessment of the cost-e ectiveness of conservation actions to provide improved guidance for the strategic allocation of future conservation e orts.

The resources available to address the global decline of biodiversity fall short of what is needed and consequently, decisions must be made as to where and how limited resources are allocated (Bottrill et al., 2008). Decision making frameworks which promote the articulation of explicit and transparent priorities, objectives and limitations are increasingly proposed and utilised (Possingham et al., 2001; Naidoo et al., 2006; Bottrill et al., 2008; Joseph et al., 2009). Decision making strategies which include economic considerations, such as the cost e ectiveness resource allocator tool, are particularly useful as they provide a transparent means of prioritising actions based on the feasibility of implementation, potential bene ts and cost (Polasky et al., 2005). While other strategies can be used to identify and rank priority species, locations, areas or objectives, cost e ectiveness is particularly valuable as the method ranks the actions which ultimately require resourcing (Joseph et al., 2009; Wilson et al., 2009; Game et al., 2013; Brown et al., 2015) and o ers a framework in which investment decisions can be defended, assessed or revised.

1.1. Overview of current conservation strategies

1.1.1. Protected areas

Creating a network of protected forests has been seen as the cornerstone of global conservation e orts for the past 100 years (Watson et al., 2014). To maintain biodiversity and protect representative ecosystems and iconic species such as orangutans, over 340,000 km^2, or 64% of the total land area of Kalimantan, the Indonesian portion of Borneo, was initially allocated to permanent mixed purpose State Forest use between 1967 and 1972 (Curran et al., 2004). As of 2013, 110,232 km^2 equating to 20.7% of Kalimantan's land mass, had been designated as protected (IUCN category I–III) (Gaveau et al., 2013). Between 2013 and May 2018, no additional national parks (IUCN category I–II) have been established in Kalimantan, however an additional 1772 km^2 has been designated and fully granted as community forest area (IUCN category III) bringing the total protected area to 112,004 km^2 (Ministry of Environment and Forestry, 2018). The extent of this protection falls short of plans for biodiversity representation across the protected area network as articulated in Indonesia's National Conservation Plan (MacKinnon and Artha, 1982) and the Indonesian Biodiversity Action Plan (Indonesia Ministry of National Development Planning, 1993). At present, designated protected areas primarily consist of land that is remote and located at high altitudes as these areas are not in high demand for land use development. This leaves few protected areas in the more densely populated areas of low altitude (Jepson et al., 2002; Gaveau et al., 2013; Brun et al., 2015) that better represent the prime habitat of orangutans and other lowland species. Areas of lowland, swamp, riverine and mangrove forest are under-represented (Jepson et al., 2002), and the few samples of these habitats a orded protection are threatened by wild res, logging, conversion and encroachment (Curran et al., 2004; Gaveau et al., 2014). Indeed, between 2000 and 2010, 1222 km^2 of these protected forests, representing 1.2% of the total protected area in Kalimantan were logged (Gaveau et al., 2013). Designated protected areas also tend to share similar soil quality attributes, including excessively drained, strongly acidic and shallow soil pro les that are poorly suited for supporting high levels of biodiversity (Santika et al., 2015).

Forest protection is included in the NAP as a key conservation activity for Bornean Orangutan (Ministry of Forestry of the Republic of Indonesia, 2009). However, due to inadequate habitat representation and the fragmented nature of Kalimantan's protected area network, only a few areas are able to adequately protect viable orangutan populations and subsequently, only 20% of the Indonesian Bornean Orangutan population is currently located within the boundaries of formally protected areas (Wich et al., 2012; Utami-Atmoko et al., 2017). Bornean Orangutans are most abundant in peat swamp forest and lowland mixed dipterocarp forest (Husson et al., 2009; Ancrenaz et al., 2016) where they require large areas (> 500 km^2) to sustain genetically viable populations of > 200 individuals (Marshall et al., 2009; Utami-Atmoko et al., 2017). This is due to a range of factors including the seasonal variability of food sources, their semi-solitary lifestyle and a low reproduction rate (van Schaik et al., 2009), although past and ongoing coexistence with people and hunting may also be contributing factors to low densities and large individual ranges (Spehar et al., 2018). Given the species' habitat requirements and poor ability to recover from population shocks, the scarcity of adequately protected forest habitats with favourable ecological conditions presents a crucial challenge for the survival of Bornean Orangutans (Miles, 2007; Wich et al., 2012).

1.1.2. Production land management

Given that the majority of orangutans are located outside of protected areas in Kalimantan, and in light of rapid land conversion for industrial and smallholder agriculture (Austin et al., 2019), strategic management of the species' remaining habitat is needed if minimising threats to survival is intended (Ministry of Forestry of the Republic of Indonesia, 2009; Wich et al., 2012; Utami-Atmoko et al., 2017). Sustainable concession development and management have been identi ed as vital for ensuring the species' persistence (Russon et al., 2001; Wich et al., 2012), while an increased focus of the Indonesian government on community-based forest management may also contribute to stabilising forest loss in production lands (Santika et al., 2017b). Such interventions could include increased designation of conservation set-asides (within palm oil, and pulp and paper concessions), selective and reduced-impact logging, and the maintenance of wildlife corridors connecting areas of high conservation value (Meijaard et al., 2010; Wich et al., 2012).

Numerous Non-Government Organisations (NGOs) and industry bodies have encouraged the adoption of orangutan-friendly practices in large-scale agricultural landscapes, recognising both Indonesia's goals for agricultural expansion and the opportunity to protect the large proportion of the orangutan population found on agricultural land (Wich et al., 2012; Ancrenaz et al., 2015). Over the past decade, some Indonesian industrial agriculture rms have embraced a range of certi cation standards as a result of government, NGO and consumer pressure (Newton et al., 2013). Despite their adoption, the e ectiveness of these programs remains uncertain (Ruysschaert and Salles, 2014; Cattau et al., 2016; Meijaard et al., 2017; Morgans et al., 2018; Carlson et al., 2018) and there is little evidence to suggest that schemes such as

RSPO have reduced the loss of orangutans (Morgans et al., 2018).

1.1.3. Orangutan rescue, rehabilitation and release

Rescue, relocation, rehabilitation and release programs are the highest profile conservation interventions for orangutan and form a key component of the NAP (Ministry of Forestry of the Republic of Indonesia, 2009 A.2; Meijaard et al., 2012). Such programs were initiated in Sabah and Sarawak (Malaysian Borneo) in the early 1960s and in Kalimantan (Indonesian Borneo) in the 1970s, with the establishment of the rescue, rehabilitation and release centre in Tanjung Puting National Park, Central Kalimantan. An additional seven centres have since been set up and continue to operate across Kalimantan. The rehabilitation centres are concerned with removing individuals from threatening circumstances, such as the illegal pet trade, potential human-wildlife conflict scenarios, or areas of pending habitat loss and fragmentation (Russon, 2009; Meijaard et al., 2012; Freund et al., 2017). In circumstances when rescued individuals are healthy and uninjured, they are relocated and released into other, supposedly safe forest areas. However, many individuals require extended veterinary care, rehabilitation and quarantine periods before reintroduction into the wild (Russon, 2009).

The funds generated from the high public profile of rehabilitation centres have most likely improved the capacity, efficiency and success rate of the rescue, rehabilitation and release process, although clear and quantified assessment of these different phases is lacking. Often, it is claimed that these programs have also aided in leveraging funds and awareness for orangutan habitat protection (Russon and Susilo, 2014; Wilson et al., 2014). However, rehabilitative care for orangutans is a long-term and costly commitment. Due to a lack of suitable habitat, the rate of individuals being admitted to these centres overall exceeds the number of orangutans being released into the wild (Russon, 2009). In addition, the overall benefit of care centres has drawn criticism as some centres fail to follow IUCN best practice guidelines for the re-introduction of great apes (Beck et al., 2007), resulting in high casualties associated with possible disease transmission into naïve populations, the adoption of inappropriate and unnatural behavioural patterns and the insufficient protection of areas in which orangutans were released (Grundmann, 2006; Russon, 2009; Russon et al., 2016).

1.1.4. In-situ community education

Poaching, hunting and human-wildlife conflict present significant threats to Bornean orangutan populations with an estimated 750–1300 animals killed each year (Meijaard et al., 2011b; Abram et al., 2015), although the numbers could be higher (Voigt et al., 2018). Poaching of orangutans for the illegal pet trade has been estimated to result in the loss of 500 infants a year (Nijman, 2005) with few surviving individuals intercepted by government authorities and rescue centres (Freund et al., 2017). The poaching practice is largely considered to be opportunistic (Meijaard et al., 2011b), with increased forest clearing and land conversion, such as for industrial oil palm and small-holder agriculture, influencing the number of reported poaching cases (Freund et al., 2017). In addition to poaching for the pet trade, orangutans are killed for food, tokens, in retribution for crop raiding and out of fear (Meijaard et al., 2011b). Village level surveys of human-orangutan interactions revealed that of the respondents who accurately identified an orangutan, 15% had witnessed agricultural conflicts with orangutans; of this category, 33% had witnessed such conflict on a weekly to monthly basis (Meijaard et al., 2011b). Negative interactions with orangutans are predicted to increase negative perceptions of the species and could lead to retaliation such as capture and killing (Campbell-Smith et al., 2010; Campbell-Smith et al., 2012; Davis et al., 2013).

In combination with forestry department officials, several NGOs attempt to address these problems by offering community-based education programs in schools, villages and production areas. These programs aim to encourage awareness of the species and their legal protection, to offer methods of alternative crop protection in smallholder farms (such as through the use of nets and noise deterrents), and to break down negative perceptions of orangutans (Campbell-Smith et al., 2010; Orangutan Foundation International, 2016; Gunung Palung Orangutan Conservation Project, 2019). Education programs have also been implemented to raise awareness of the intrinsic value of orangutans and the potential economic value of orangutan-focused ecotourism ventures (Ancrenaz et al., 2007; Nilsson et al., 2016).

1.1.5. Need to optimise conservation investments

Orangutan populations are continuing to decline even with decades of investment from government and non-government organisations alike (Meijaard et al., 2012). Scarce conservation resources must be strategically allocated if we are to maximise conservation gains and avoid species extinctions (Santika et al., 2017a). To date, uncertainty surrounding population distribution, size and trends, spatial variation in threats and a lack of transparency concerning conservation investment and effectiveness have hindered strategic conservation planning (Iacona et al., 2018). In light of new population estimates, this paper aims to identify population distribution and decline across differing land uses, quantify the cost of commonly employed conservation strategies and assess opportunities for future conservation spending to maximise returns on investment.

2. Methods

Our methodology employs a three-step approach: to assess changes in orangutan distribution and density across different land uses in Kalimantan, calculate the costs and relative benefits of commonly employed conservation actions, and identify priorities for strategic and cost-effective future conservation investment.

2.1. Population distribution and decline across major land uses

We used an orangutan density and distribution model developed by Santika et al. (2017a) to map changes in populations across Kalimantan between 1999 and 2014. This data set predicts orangutan presence based on a combination of orangutan nest count data, and interview surveys of direct orangutan sightings (Santika et al., 2017a). These data were overlaid with six land use data shapefiles in ARC GIS version 10.0 (ESRI, 2012).

Major land use types included protected areas, forest moratorium areas, timber, logging and palm oil concessions, for which we obtained boundaries for 2014 from the Indonesian Ministry of Forestry through the World Resources Institute. Boundaries for RSPO-certified sustainable palm oil concessions were also included (Morgans et al., 2018). Overlaps in land use layers were identified and separated; for example, many areas included in the Indonesian forest moratorium are already designated protected areas (e.g. Tanjung Puting, Sebangau and Gunung Palung National Parks). Subsequently, these areas were considered only as national parks, as the forest moratorium is unlikely to be able to afford these areas with additional, long-term protection above that already occurring under protected area designation. Similarly, oil-palm concessions that had been certified by the Roundtable on Sustainable Palm Oil (RSPO) were separated from non-certified concessions.

2.2. Conservation costs and benefits to orangutan populations

Ten primary conservation actions were identified from the Indonesian NAP and the annual reports of three NGOs undertaking conservation actions for orangutan (The Orangutan Project, Bornean Orangutan Survival and the Orangutan Foundation International). Actions included habitat purchase, habitat restoration, habitat purchase and restoration, protected area establishment, protected area management, production land management (i.e. timber and logging concessions), RSPO certification, community education, monitoring and enforcement, as well as orangutan rescue, rehabilitation and release

Table 1
Common conservation actions for Bornean Orangutan.

Action	De nition
Land purchase	The private purchase of land for the purpose of maintaining habitat.
Restoration	Intensive, strip, or gap planting in areas that have been severely or moderately degraded.
Land purchase & restoration	The private purchase of land that have been severely or moderately degraded for the purpose of restoring native vegetation structure and composition.
RSPO conversion	The process of applying for and receiving RSPO certi cation.
Production land management	The process of monitoring timber or pulp and paper concessions in a manner that reduces environmental impact (e.g. through reduced impact selective logging).
Release	The process of rescuing orangutans for the purpose of providing rehabilitation before releasing back to the wild.
Monitoring and protection	Professional 'wildlife wardens' who are trained and privately employed (e.g. via NGO's) for the purpose of undertaking surveillance activities in national parks and intercepting illegal activities.
Community education	The provisioning of information to schools, community groups or employees for the purpose of raising awareness of the legal status of orangutan and prevent negative attitudes towards the species.
Protected area establishment	The designation and o cial gazettement of protected areas ranging from IUCN category I–VI.
Protected area management	Improved management and operation of pre-existing protected areas (IUCN category I–VI) through increases in funding, personnel or resource allocations.

Table 2
Costs of major conservation activities.

Action	Average cost USD (*lower CI–upper CI*)	Unit	Reference(s)
Land purchase	250,199 *(234,274–267,923)*	km^2	The Orangutan Project (2015); Bornean Orangutan Survival (2014, 2015), Orangutan Foundation International (2011, 2014, 2015).
Restoration	559,784 *(238,594–880,973)*	km^2	Bornean Orangutan Survival (2012, 2013, 2014, 2015, 2016); Budiharta et al. (2014).
Land purchase & restoration	935,807 *(552,926–1,318,689)*	km^2	The Orangutan Project (2015), Bornean Orangutan Survival (2014, 2015), Orangutan Foundation International (2014, 2015), Budiharta et al. (2014).
RSPO conversion	4756 *(1080–8432)*	km^2	Levin et al. (2012), Preusser (2015).
Production land management	128 *(92–164)*	km^2	Applegate (2002), Wilson et al. (2010).
Release	26,220 *(8292–44,149)*	Per Orangutan	Orangutan Foundation International (2011, 2012, 2013, 2014, 2015), Bornean Orangutan Survival (2012, 2013, 2014, 2015, 2016), The Orangutan Project (2014, 2015, 2016), Wilson et al. (2014).
Monitoring and protection	23 *(7–14)*	Per day	Sugardjito and Adhikerana (2010).
Education	88 *(26–151)*	Per person	Orangutan Foundation International (2011, 2012, 2013, 2014, 2015), The Orangutan Project (2014, 2015, 2016).
Protected area establishment	282, 984 *(218,290–347,677)*	km^2	Dudley et al. (2007), Wilson et al. (2010), Budiharta et al. (2014).
Protected area management	680 *(268–1091)*	km^2	McQuistan et al. (2006), Wilson et al. (2010), Gaveau et al. (2013).

(Table 1). Data concerning the costs of these actions was obtained through the analysis of primary literature and NGO annual reports (Tables 2 & A1). Primary literature included costs of orangutan rescue and release (Wilson et al., 2014), restoration (Budiharta et al., 2014), monitoring and protection units (Sugardjito and Adhikerana, 2010), and alternative land use (Wilson et al., 2010). Cost data extracted from NGO annual reports between 2011 and 2016 included a range of interventions such as orangutan rescue, rehabilitation, release, land purchase, habitat restoration and community education. The outcomes of actions as reported by NGO's were extracted to calculate costs per relevant unit. Such measures included the area of habitat (km^2) purchased, the number of orangutans released or the number of community members that had been educated (Table A1). In circumstances where costs were reported but not attributed to an outcome and vis versa, data was excluded as we were focused on calculating costs per unit. Data reported in the primary literature and annual reports were assumed to be accurate and credible. In instances where multiple values were reported either across years or from multiple organisations, the cost per unit was averaged and 95% con dence intervals calculated to account for variation (Table 2). Three interactions of the resource allocator tool were then parameterised using high, low and average cost values respectively. Where necessary, currency was converted to USD dollars based on the average annual exchange rate for a given period (e.g. 1 USD = 8989 IDR 2015–2016).

After the average cost per square kilometre of private land purchase and protected area establishment was obtained, opportunity costs were then assigned. Assuming private land purchase occurs in optimal intact forest landscapes, the predicted value of foregone alternative land use revenue is US$226, 800 per square kilometre (Ruslandi et al., 2011; Budiharta et al., 2014) (Table 2). Similarly, the establishment of protected areas also includes opportunity costs associated with lost income from extractive land uses, as areas optimal for orangutan conservation are also likely to feature commercially viable timber forests and agricultural land (Jepson et al., 2002; Runting et al., 2015). In addition to this, the establishment of new protected areas is likely to have designation costs associated with stakeholder consultations, bureaucracy and political process surrounding changes to land designation and boundary demarcation, as well as upfront costs associated with land purchase and compensation. Subsequently, protected areas were assigned a higher opportunity cost of US$263,400 per square kilometre (Bruner et al., 2004; Wilson et al., 2010).

2.3. Resource allocation parameters and analysis

As one of several methods of prioritising conservation e orts, project prioritisation based on cost-e ectiveness is increasingly used to manage threatened species and ecosystems where the ultimate objective is to identify the action or suite of actions that can give the most benefit (i.e., increased species persistence) per unit cost (Di Fonzo et al., 2017). The cost-effectiveness resource allocator tool allows for the transparent identification of a suite of actions within a defined budget and time frame, where assessments are based on the cost of actions and the likelihood of success. Assessing the cost-effectiveness of threatened species conservation has previously been used to identify and implement management strategies in New Zealand (Joseph et al., 2009) and in the Australian state of New South Wales (Szabo et al., 2009). Recently, the approach has been adapted into a Microsoft Excel tool to facilitate practitioner use and interpretation (Di Fonzo et al., 2017). The tool requires users to parametrise overall budget availability, the expected costs of potential conservation strategies and expected benefits to a target species or population. Using these parameters and accounting for uncertainty, the tool then ranks potential conservation actions, determining which actions should be prioritised to maximise returns from conservation investment (Di Fonzo et al., 2017).

Three budget scenarios over a ten-year period were examined. The low budget scenario was capped at US$20 million per year, reflecting recent estimates of conservation funding for the species (Meijaard, 2014). The intermediate budget scenario of $80 million per year reflects existing funding plus potential contributions from private industry in the forms of conservation set-asides and sustainable operating practices (Nantha, 2014). The high budget scenario was capped at $160 million per year, or $1.6 billion over the 10-year planning period and representing < 0.001% of Indonesia's annual GDP (World Bank, 2017). The generation time for the species was set to 25 years, reflecting current IUCN estimates (Ancrenaz et al., 2016).

The ten conservation actions previously identified were included in the cost-effectiveness resource allocator as independent action strategies and where relevant, combined to form complementary strategies. For example, land purchase was included as an independent strategy as well as a component of a combined strategy involving orangutan rescue and release (Table 3). The inclusion of these strategies as both individual actions and complementary action strategies reflects the diversity of programs currently undertaken for the conservation of the Bornean orangutan, and the variation in the extent of the collaboration between projects and organisations (Morgans et al., 2017). A total of 15 conservation strategies were identified and assessed (Table 3). Due to variations in cost and capacity, the anticipated size of conservation action strategies varied, for example the size of restoration activities was capped at 1000 km^2 while improved management of production land was capped at 25,270 km^2. The number of orangutans estimated to benefit from each conservation strategy was scaled in line with the anticipated size of each strategy and the density of orangutans found in targeted land use types (Table 4).

The median annual salary for personnel was estimated to be US $25,000 per year, reflecting the Indonesian median income for highly skilled workers of US$4000 per year (Indonesian Ministry for Manpower and Transmigration, 2017), average annual staffing expenditure (reported in NGO annual reports) and average annual income of expert international personnel. The annual allocation of personnel was estimated to be 287,500 days, the equivalent of 1200 people undertaking full-time, paid employment at 230 days per year. These allocations were differentially attributed to each conservation strategy, with allocations based on staff numbers reported by conservation organisation in annual financial reports (Table 4).

To estimate the potential benefit of conservation strategies, the cost-effectiveness resource allocator tool compares the population trend of the species in the absence of any strategy, with the predicted benefits achieved by each single or combined strategy. The benefits of each of the 15 strategies are based on the predicted number of mature individuals and the predicted population decline over the 10-year planning period across three scenarios – best case, worst case and most likely. To calculate population trends for the planning period, population declines between 2004 and 2014 were projected forward, with a best-case scenario of between 10 and 15% decline depending on land use type (Tables A2 & A3) and a worst-case scenario of 25% decline over the planning period. Benefits associated with the implementation of conservation strategies were calculated independently of budget scenarios.

Population density and distribution data, along with costs of conservation actions were used to parameterise costs and benefits for each of the conservation strategies. Best-case scenario calculations for each of the conservation strategies were based on the estimated population in the land use type the strategy would target, current population trends within these areas, the anticipated size of the conservation strategy and the corresponding number of orangutans that could be benefitted (Tables 4, A2). Under the best-case scenario, it was assumed that the conservation strategy was optimally implemented so that, for example, the establishment of new protected areas would occur in appropriate habitats for orangutan and where large populations exist (i.e. areas currently covered by the Indonesian Forest Moratorium). Population trends under the 'most likely' scenario fell between worst-case and best-case scenarios and varied depending on the size of the conservation strategy and the resulting number of adult orangutan that may benefit assuming implementation may be somewhat less than optimal. For example, rescue and release strategies are only likely to achieve small population benefits over the planning period where as the establishment of a new protected area or improved protected area management would likely benefit a greater number of individuals (Table A3). The worst-case estimate of a 25% decline was kept consistent across all strategies to account for the possibility that while a strategy might be implemented it might not necessarily be optimally implemented or effective. Although some conservation strategies may be associated with more risk than others, we did not expect any conservation actions to further exacerbate overall projected population declines within the 10-

Table 3
Individual actions and resulting strategies for Bornean orangutan conservation assessed using the cost-effectiveness resource allocator tool. Strategies reflect individual conservation actions (e.g. strategy 1, land purchase) and where relevant, combined complementary actions (e.g. strategy 7, land purchase and release).

Action	Strategy														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1) Land purchase															
2) Restoration															
3) Land purchase and restoration															
4) RSPO conversion															
5) Production land management															
6) Release															
7) Monitoring and enforcement															
8) Education															
9) Protected Area establishment															
10) Protected area management															

Table 4
Conservation actions, locations and predicted population bene ts. Population density and distribution data obtained from Santika et al. (2017a).

Conservation strategy	Land use type targeted by strategy	2014 population estimate of land use type	Projected rate of decline (%)	Employment allocation	Anticipated size of deployed strategy	Estimated maximum number of orangutan to bene t
Land purchase	Non-classi ed land use	58,000	20	11,500	2160 km^2	200
Restoration	Non-classi ed land use	58,000	20	11,500	1000 km^2	100
Land purchase and restoration	Non-classi ed land use	58,000	20	11,500	1000 km^2	100
RSPO conversion	Non-certi ed Palm oil concessions	2650	19	34,500	4339 km^2	503
Production land Management	Logging concessions	11,630	20	35,000	25,270 km^2	2326
Re-release	Rescue centres	1200	N/A	11,500	1200 orangutan	1080
Monitoring and protection	Protected Areas	10,800	20	11,500	4015 patrols	500
Education	Non-classi ed land use	58,000	20	11,500	125,000 people	500
Protected area establishment	Forest Moratorium areas	3050	40	80,000	12,076 km^2	1200
Protected area management	Existing protected areas	10,800	20	69,000	27,171 km^2	2100

year project planning time frame. Con dence in estimates ranged from 40 to 80% depending on pre-existing evaluations and data availability (Joseph et al., 2009). For example, a high level of con dence was associated with estimations of small population bene ts likely to be obtained through the release of captive orangutans in the absence of additional actions (Siregar et al., 2010). Whereas a low level of con dence was associated with bene ts to the population as a result of community education, due to limited evidence documenting the impact of education strategies have had in achieving positive population outcomes (Schultz, 2011) (Table A3). The cost-e ectiveness of conservation strategies was ascertained by ranking actions based on predicted additional extant years resulting from an action (i.e. the di erence between rates of population decline when a strategy is implemented compared to when it is absent) divided by the cost of the action. The highest ranked actions were then identi ed based on cumulative costs and budget constraints (Di Fonzo et al., 2017) resulting in a suit of recommended actions that should be prioritised to maximise species persistence. Due to variation in cost data (Table 2), this analysis was undertaken three times re ecting the low, average and maximum reported cost estimates of each action.

3. Results

3.1. Population density and distribution

The overall orangutan population in the Indonesian provinces of Borneo (North, East, South Central and West Kalimantan) between 2009 and 2014 was estimated to be 58,000, a 30% decline from the 1999–2003 estimates, which represented a loss of 2% (1700 individuals) per year. Over the 15 years examined, the greatest relative rate of population decline occurred in areas now covered under the Indonesian Forest Moratorium (59.7%), the second highest rate of population decline occurred equally in two separate land use types, areas that have become RSPO-certi ed oil palm plantations and logging concessions (33% each). Oil palm plantations and protected areas experienced the next greatest loss at a rate of 28.8% and 28.6% respectively (Fig. 1a). Of the examined land use types, the majority of the remaining populations are predicted to reside in logging concessions (27%), followed by Protected Areas (19%) and palm oil concessions (including areas legally gazetted for oil palm but not yet developed) (16%) (Figs. 1b, 2, Appendix A2).

3.2. Conservation costs and e ectiveness

Common interventions used for Bornean orangutan conservation included land purchase, restoration, conversion to certi ed sustainable palm oil, management of production lands, orangutan rehabilitation and release, monitoring and protection, community education and protected area establishment management (Table 1). Average costs for conservation actions ranged from US$23 per day for monitoring and protection units to US$282,984 per square kilometre for protected area establishment. Community education focused on orangutan conservation was found to cost on average $88 per person, while orangutan rescue, rehabilitation and release was found to cost $26,220 on average per orangutan, in line with estimates made by Wilson et al. (2014) (Tables 2 and A1).

3.3. Project prioritisation

Of the 15 strategies, three were found to meet the critical cost-effectiveness threshold in all budget scenarios (i.e. the highest number of additional extant years per dollar spent). These strategies included monitoring and enforcement, education and production land management. Two additional strategies (release and RSPO conversion), may also meet the cost-e ectiveness threshold in all scenarios if the costs of these strategies are equal to, or below the average reported cost (Fig. 3).

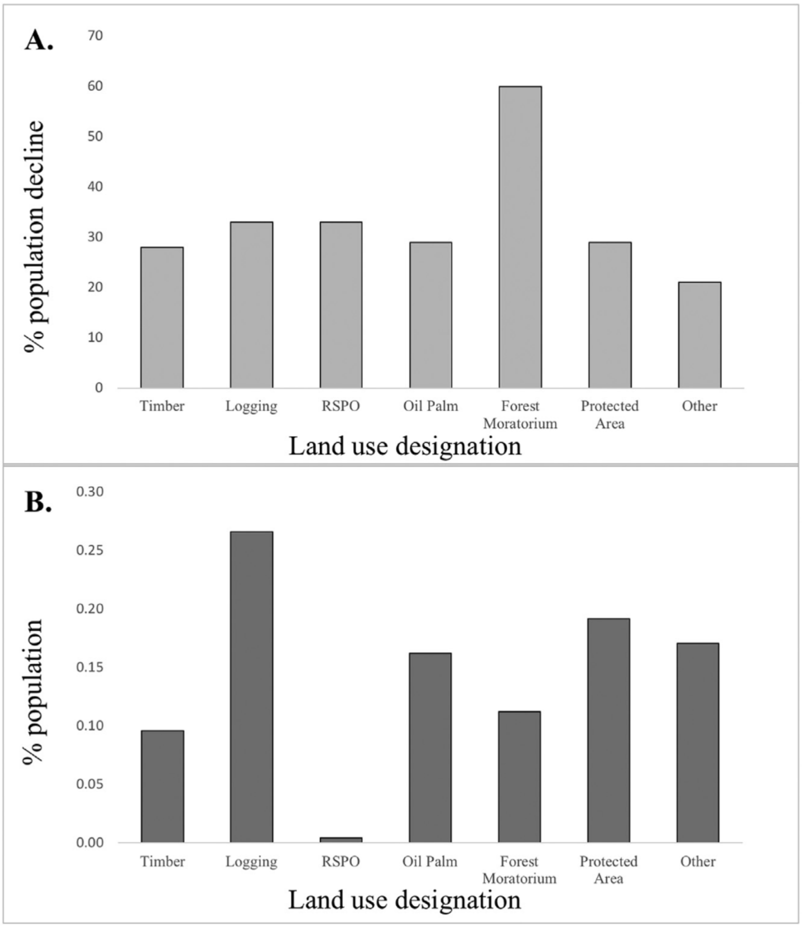

Fig. 1. (A) Population declines of orangutan across major land use types between 1999 and 2014 and (B) distribution of remaining orangutan populations across major land use types in 2014.

Under the intermediate budget scenario ($80 million per year), additional actions of education combined with production land management, and education combined with RSPO certi cation were found to be cost e ective. Protected area management may also be cost-effective if costs for the action are equal to or below the reported average (Fig. 3). The resource allocator tool calculates the cumulative impact of strategies identi ed as meeting the cost-e ectiveness threshold on species survival (Di Fonzo et al., 2017). In this scenario, the implementation of eight strategies in combination will improve the expected survival of orangutan by 60 years beyond the 30 years expected extant survival in the absence of any strategy and 25 years beyond expected species survival under the low budget scenario. The total cost of achieving this outcome is estimated to be US$352 million over the 10-year project period.

4. Discussion

4.1. Optimizing orangutan conservation strategies

In the absence of any conservation activity, our analysis predicts substantial declines in Kalimantan's Bornean orangutan within the next 20 years, further corroborating estimates calculated by Voigt et al. (2018). If current trends continue, the most susceptible populations include those residing in logging concessions, followed by populations in areas currently included in the Indonesian Forest Moratorium. These two population types would be expected to decrease by approximately 3400 individuals and 2600 individuals respectively over the next 10 years. Strategic allocation of conservation resources within the de ned project planning period and budget could signi cantly improve outcomes for the Bornean orangutan in Kalimantan, increasing the species' longevity by 60 years under the intermediate budget scenario. Populations most likely to bene t from the cost-e ective interventions identi ed include those found in protected areas, logging concessions, timber concessions and forest remnants outside of concessions.

The cost-e ectiveness resource allocator tool estimates several interventions to be cost-e ective at both the low and intermediate-budget scenarios. Such interventions included investment in monitoring and enforcement, education, release, production land management, conversion to RSPO-certi ed oil palm plantations and protected area management (Fig. 3). Investment in orangutan release and land purchase was found to be cost-e ective under the high budget scenario but beyond the cost-e ectiveness threshold of the intermediate budget scenario. Collectively, these results suggest that investment in activities focused on preventing further habitat destruction and population declines are more cost-e ective than investing in remediation activities.

The identi cation of monitoring and enforcement, as well as education as cost-e ective conservation interventions, points to the potential bene ts of directly addressing major threats to orangutan persistence (i.e. hunting and killing). Improved monitoring in protected areas, public campaigns about hunting and killing of orangutans, interception of illegal hunting activities and enforcement of pre-existing legislation regarding orangutan poaching and killing are likely to have positive impacts for species protection. Education programs reinforcing the intrinsic and economic value of the species, as well as their legal

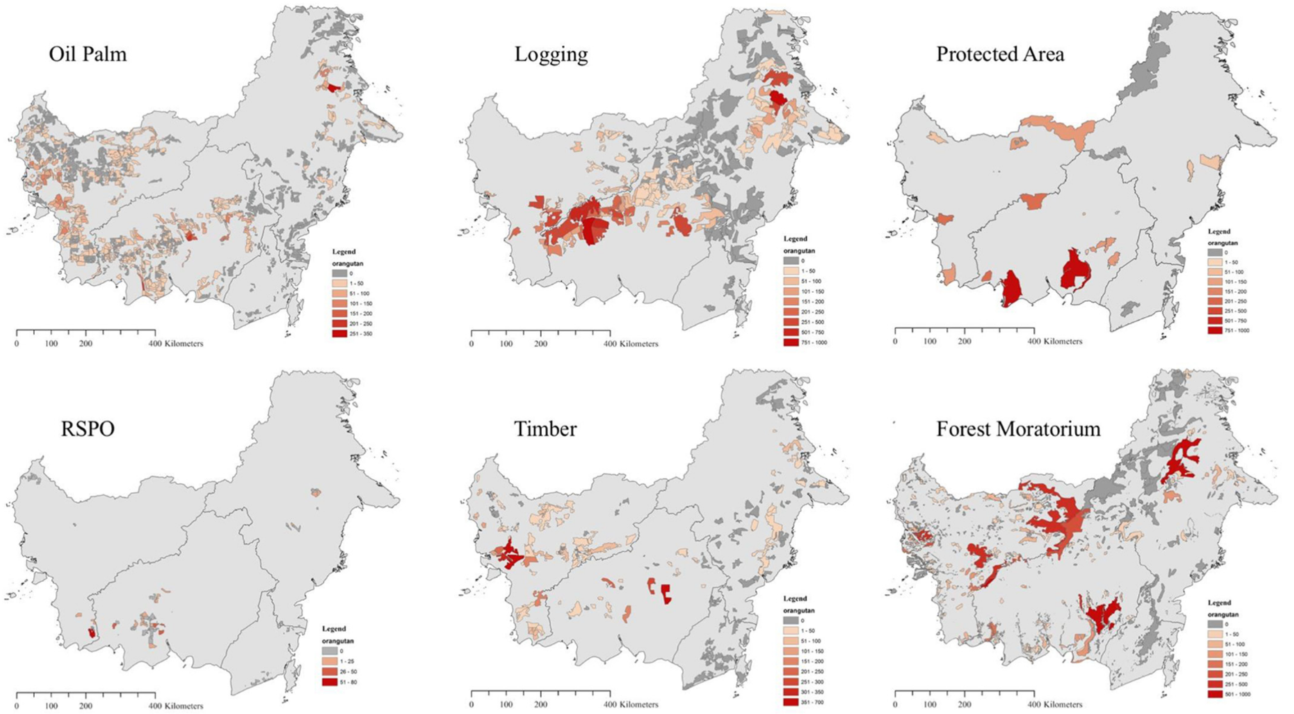

Fig. 2. 2011–2014 Current Bornean Orangutan distribution and density across major land use types in Kalimantan. Boundaries for major land use types displayed with varying intensity of colour depicting higher population densities.

protection, could complement increased monitoring e orts, particularly if delivery is expanded to law enforcement o cials (Freund et al., 2017). As both of these strategies address primary threats to orangutans, they are more likely to have a greater impact by reducing the loss of this late maturing and long-lived species than strategies focused on mitigating existing damage (Margules and Pressey, 2000; Tabarelli and Gascon, 2005). Nevertheless, considerable uncertainty remains in regard to the long-term success of these strategies. For example, education programs are often based on the assumption that knowledge will lead to positive behaviour change, however, there is limited evidence to support such claims with few evaluations of education program e ectiveness undertaken (Kollmuss and Agyeman, 2002).

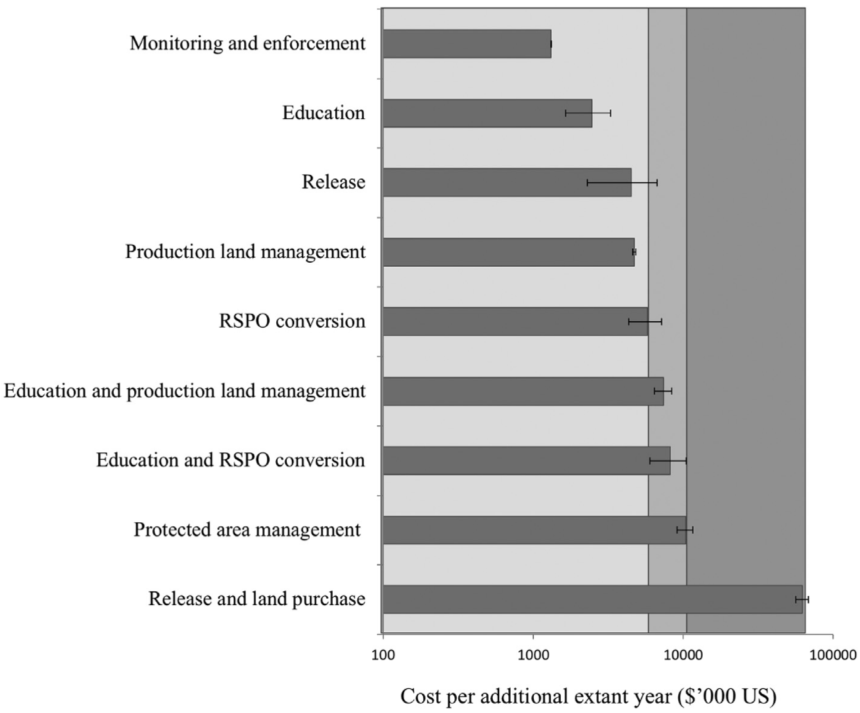

Fig. 3. Cost-e ectiveness of conservation strategies over the 10-year planning timeframe in three budget scenarios. Light grey box incorporated cost e ective strategies under a low budget scenario of US$20 million p.a. Mid-grey box incorporates cost e ective strategies under an intermediate budget scenario of US$80 million p.a. Dark grey box incorporates cost e ective strategies under a high budget scenario of US$160 million p.a. Cost e ectiveness is calculated by the number of expected additional extant years achieved by each strategy divided by total cost. Error bars depict 95% con dence intervals in costing estimates. (For interpretation of the references to colour in this gure legend, the reader is referred to the web version of this article.)

Sustainable management of production land (i.e. logging concessions) and the sustainable management of palm oil concessions (via RSPO certification) were found to be cost-effective under all budget scenarios. In addition to improved environmental sustainability, reduced impact logging (RIL) practices have been found to result in improved operational efficiency for logging companies due to higher retrieval rates of felled trees and reduced damage to residual stands of future crop trees (Applegate, 2002; Holmes, 2014). However, while the profitability of RIL practices has been found to be comparable to conventional logging practices in Latin America, there is evidence to suggest the contrary in South East Asia (Indrajaya et al., 2014; Holmes, 2014). Sustainable management of oil palm plantations has also been shown to correspond with higher efficiency and profitability, however, uncertainty remains over the environmental benefits of RSPO certification (Morgans et al., 2018). Analysis of orangutan populations across land uses during the past 15 years revealed greater than expected population declines in areas that have become RSPO certified than other palm oil concessions. This is likely to be a consequence of the extensive clearing that has occurred in RSPO concessions before receiving certification (Morgans et al., 2018), and the number of designated, non-certified, palm oil concessions that are currently inactive, thus retaining habitable forest remnants (Meijaard et al., 2017). Although there is no significant evidence to suggest certified and sustainably managed plantations can conserve orangutan populations better than non-certified concessions, improvements to the RSPO certification scheme may result in better-managed plantations in the near future (Meijaard et al., 2006; Meijaard et al., 2010; Wich et al., 2012; Morgans et al., 2018).

Investment in improved management of protected areas was estimated to be cost-effective in both the intermediate and high budget scenarios. Current expenditure on protected areas in Indonesia equals US$223 per km^2 (US$156 from government and US$67 from NGOs) (McQuistan et al., 2006; Dudley et al., 2007). This investment is significantly less than what is invested in other protected areas in South East Asia and far less than what is ultimately recommended for Indonesia to reach Aichi Biodiversity Targets (Gaveau et al., 2013). In light of current spending shortfalls, even moderate additional investment in established protected areas will help ensure the maintenance of long-term habitat for the 20% of Bornean orangutans found within protected areas. The cost-effectiveness of improved habitat management is also reflected in the finding of monitoring and protection units as the single most cost-effective action in all budget scenarios. This is a result of the relatively inexpensive nature of increasing patrols, and the number of illegal direct and indirect activities increased enforcement could prevent. The identification of improved management and monitoring as priority investments supports Freund et al.'s (2017) recommendation to increase government expenditure and Pandong et al.'s (2019) recommendation to increase inter-agency collaboration for addressing wildlife and forest crimes.

An alternative mechanism for habitat management and protection may be found in community forest managed programs. Community forest allocations (*Hutan Desa*) in Kalimantan contain high proportions of peat forest habitats and experience less deforestation than other land use types, except in extreme dry conditions associated with El Niño years (Santika et al., 2017b). The Indonesian Government has committed to increasing these areas by 12.7 million hectares by 2019 as part of the social forestry initiative. The expansion of this land use type may offer a cost-effective means of increasing the persistence of wild orangutans and connect existing protected areas, an important opportunity for consideration in future orangutan conservation planning frameworks pending further evaluation of the schemes impact.

Of the strategies involving orangutan rescue and release actions (i.e. rescue; rescue and land purchase; rescue, land purchase and restoration; rescue, land purchase, restoration and monitoring) rescue and release in the absence of complementary strategies was found to be the most cost-effective, followed by the combination of release and land purchase. Despite the low population benefits likely to be achieved by rescue and release when undertaken in isolation in terms of additional extant years for the species, this result is likely due to the high costs associated with the additional complementary actions of land purchase, restoration and monitoring as well as the marginal additional benefit this increased expenditure would have for the overall population. In addition, the majority of individuals in rescue centres are immature and thus require long term care prior to release. Presently, rehabilitated individuals must be released into areas devoid of wild orangutan populations, to reduce risks such as disease transfer (Indonesian Government Ministerial degree, 1995; Beck et al., 2007; Russon, 2009), although many orangutans are released into existing wild populations (e.g., Kutai NP, Tanjung Puting NP and Bukit Baka/Bukit Raya NP). Regardless of the rate and success of releases, rehabilitation programs in isolation are therefore unlikely to result in the establishment of viable wild populations or increase the viability of existing populations (Russon, 2009). Rescue, rehabilitation and release programs are important for raising funds and public awareness for orangutan conservation, while also providing urgent treatment to injured, orphaned and displaced individuals (Meijaard et al., 2012; Russon and Susilo, 2014; Wilson et al., 2014). However, these activities do little to combat direct threats to orangutans, while shifting the attention from the need to better protect wild populations and their habitats. Furthermore, some of the practices, such as translocation can contribute to further fragmenting meta-populations found in non-protected forests. If direct threats are not addressed, the number and rate of orangutans being placed into rescue centres will continue to grow faster than the rate of those being released. Moreover, these rehabilitation and release strategies can only be considered a cost-effective conservation intervention if individuals are being released, and survival rates are high (we note that there is limited quantitative information of post-release survival rates, especially in wild-to-wild translations). This can only be achieved if the initial threats that drove orangutans into these centres are mitigated and viable native habitat remains available.

Each of the conservation strategies included in the analysis was assumed to reduce population declines or at worst, make no further contribution to population decline. However, given the uncertainty regarding several of the actions included, the risk of perverse outcomes from ineffective or improper implementation of actions should be considered (Regan et al., 2005; Tulloch, 2015). With many extant populations of orangutan now in decline and with poor meta-population viability (Utami-Atmoko et al., 2017), there is little room for error in future conservation initiatives efforts. For example, the release of a diseased individual into a naive population may cause significant further population declines, particularly if pre-existing populations are small and isolated, overcrowded, or exposed to frequent disturbance (Utami-Atmoko et al., 2017). For this reason, it is vital that conservation efforts follow precautionary practices based on the best available evidence (Regan et al., 2005; Cooney and Dickson, 2012).

Our use of the cost-effective resource allocator tool illustrates a transparent means of allocating scarce conservation resources for the conservation of the Bornean orangutan. To date, conservation strategies for the species have been criticised for limited effectiveness and a lack of effective coordination between stakeholders and projects (Rijksen and Meijaard, 1999; Fisher, 2010; Meijaard et al., 2012; Morgans et al., 2017). The cost-effectiveness resource allocator methodology allows for a coordinated approach based on available information and with explicit limits on expenditure and resources. Although we have defined the project time frame to be 10 years and applied the approach on a broad landscape scale, the cost-effectiveness methodology allows for adaptive management and adjustment of project plans as new or improved data become available. The methodology can be also applied on a finer scale to compare the cost-effectiveness of conserving various sub-populations. In addition, the method could provide additional decision-making guidance in circumstances where priority populations have been previously identified based on attributes such as genetic importance, threat intensity or extinction risk (Joseph et al., 2009; Di

Fonzo et al., 2017). Such fine scale application for target populations may also provide the additional benefit of reducing uncertainty through improved information.

4.2. Caveats

It is important to note caveats to the estimated costs of conservation actions included in our analysis. Our sample of investment data was primarily based on data from only three orangutan sanctuaries and some limited information on government spending, and thus excluded other non-governmental expenditures (including from NGOs not focused on rehabilitation and release), as well as those made by the private sector. We also note the uncertainty regarding the effectiveness of rescue and release strategies, especially with regard to the associated largely unknown mortality rates. A further caveat is that our analysis assumes a homogeneous cost of actions with an annual discount rate of 3% to account for inflation over the planning period, however, the cost of protected area establishment and management is unlikely to be homogeneous across all landscapes, with diminishing costs per hectare as protected area size increases (Balmford and Whitten, 2003; Bruner et al., 2004). Costs associated with land purchase are also likely to vary considerably due to location, current land use, potential future land use, and level of fragmentation (Bruner et al., 2004). Within our analysis, opportunity costs were included in estimates for protected area establishment, sustainable land use, private land purchase and restoration, reflecting estimates published in scientific literature and grey literature (Wilson et al., 2010; Levin et al., 2012; Budiharta et al., 2014). Although in this analysis, opportunity costs were assumed to be homogeneous across individual actions, these costs are also likely to vary across landscapes. In follow up studies we are further refining the cost and effectiveness data, allowing more precise estimates of strategy cost-effectiveness.

There are also several limitations concerned with the application of this protocol to orangutan conservation. Such limitations are primarily due to limited data availability, particularly regarding population trends, spatial variation in threats such as killing, land use designation, and the costs and effectiveness of various actions. Typically, the cost-effectiveness resource allocator approach requires the estimation of actual population sizes from a range of experts. Our substitution of this data with a population model is necessitated by the high costs of sampling (Ancrenaz et al., 2004; Marshall et al., 2009), variability among assessments (Kuhl et al., 2008; Mathewson et al., 2008) and an urgent need for a strategic approach in the absence of perfect estimates (Kuhl et al., 2008; Meijaard et al., 2011a, 2011b). Nevertheless, our population model provides a valuable proxy, with model findings recently corroborated by Voigt et al. (2018). Similarly, land use allocations in Indonesia are known to be poorly defined (Brockhaus et al., 2012; Sahide and Giessen, 2015). Subsequently, the accuracy of land use maps is less than certain. Cost estimates for conservation actions were also highly variable. Transparent information concerning the cost of conservation actions and their relative benefits was difficult to obtain due to incomplete reporting of costs and resulting impacts (see Table A1). There are also additional challenges associated with the translation of indirect benefits into tangible outcomes for conservation targets, for example how providing education to a certain number of people will influence orangutan survivorship (Schultz, 2011).

5. Conclusion

The conservation community is frequently criticised for insufficient reporting and transparency (Sutherland et al., 2004; Ferraro and Pattanayak, 2006; Iacona et al., 2018). This often occurs as a result of inadequate operational capacity and a high rate of staff turnover, therefore limiting opportunities for robust and sustainable reporting methodologies. Our analysis provides an important demonstration of how accurate reporting and good-quality data can inform decision-making and lead to a more effective allocation of resources. Certainty and confidence in the conclusions drawn by project prioritisation protocols can be greatly improved with the availability of better data concerning both costs and effectiveness of conservation actions. The use of improved methods for program evaluation (e.g. Sutherland et al., 2018) and financial reporting for organisations working in conservation (e.g. Iacona et al., 2018) will help to facilitate this.

Continued and strategic investment in conservation strategies is vital if we are to ensure the persistence of the Bornean Orangutan in Kalimantan over the next decade and into the future. Strategies such as education and improved monitoring and enforcement offer valuable and cost-effective mechanisms for protecting the species. The adoption of revised land management practices is required, as inactive and uncleared concessions provide important strongholds for the species (Meijaard et al., 2017). The availability of improved cost and effectiveness data will allow for the modification of specific conservation schemes to enhance effectiveness. Our paper presents a preliminary assessment of programs and strategies aimed at conserving the Bornean orangutan. We provide recommendations for future management using a strategic decision-making tool – the cost-effectiveness resource allocator – to integrate financial considerations into management strategies. Our results reveal that the strategic allocation of conservation resources can lead to positive outcomes for species management over the next decade if effectively implemented. To ensure the success of such an approach, a coordinated, landscape-level approach is required.

Declaration of competing interest

The authors declare no conflict of interest.

Acknowledgments

We acknowledge the Australian Research Council Centre of Excellence for Environmental Decisions for funding and support. CLM was supported by an Australian Research Training award, KAW was supported by an Australian Research Council Future Fellowship. We thank editors and reviewers for providing valuable inputs on our manuscript.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.biocon.2019.108236.

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