NERC Innovation Project: Decision support for restoring ecological networks in rapidly developing, biodiverse countries

REPORT ON CASE STUDY: Scenarios for restoration of degraded tropical forest in a 'corridor' between Mount Halimun and Mount Salak, in West Java

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Version 1

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A visit to Kampung Sukagalih, on the southern edge of the TNGHS wildlife corridor, to observe a successful forest restoration project. (Photo credit to L.Cole, November 2018.)

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I. Introduction to the Project

Condatis is a modelling program for use in landscape planning. It was developed by Dr Jenny Hodgson, based at the University of Liverpool, over five years ago, in response to an evident need to better understand the implications of climate change on biodiversity, and how we might mitigate any negative impacts.

Specifically, Condatis was developed to deal with the dual challenges of habitat fragmentation and climate change. These phenomena are causing there to be a reduced amount and connectedness of habitat, which in turn, makes it more difficult for populations to shift to track changes in temperature. UK conservation organisations concerned with supporting species' survival under ongoing changing environmental conditions, such as Buglife, were looking for a tool to assist them in planning restoration projects that would be effective in connecting up habitats for different target species on a landscape scale. In addition, there is increasing pressure at the global scale, from international environmental policies such as the New York Declaration on Forests, the Bonn Challenge, the Paris Climate Agreement, and the Sustainable Development Goals, to restore forest habitat for the purposes of climate change mitigation through enhanced carbon storage, the conservation of biodiversity and the achievement of sustainable and equitable development. Condatis was developed to address landscape planning challenges both local to the UK and experienced across the world.

A variety of UK conservation organisations were involved in the testing of the tool during its early development, and have been involved in ongoing feedback exercises and subsequent advancements.

These relationships were predominantly built as part of a NERC-funded Knowledge Exchange Fellowship, led by Dr Katherine Allen. This ongoing project involves working with stakeholders to introduce them to and support their use of Condatis, and strategic landscape planning in general. Various organisations are now using Condatis to guide landscape management, including Natural England and Natural Resources Wales.

However, the Condatis Network has not been promoted or used within a developing world, tropical context, where ecological and socio-economic conditions can be quite different. This report forms one of the pieces summarising the activities and outputs of the NERC-funded Innovation project entitled: *Decision support for restoring ecological networks in rapidly developing, biodiverse countries*, which ran from November 2017 until April 2019. The main aim of the project was *to facilitate sustainable land-use planning for tropical developing countries under climate change*, with the following goals:

i. Create new, accessible **decision support methods**;
ii. Demonstrate how conservation decisions can be supported in our partner organisations through **three collaborative case studies**; and,
iii. Create a **freely available web application** for our decision support tool and ensure its long-term accessibility, especially for users in developing countries.

Goals (i) and (iii) have been achieved through the development and launch of Condatis Version 1.0, which can be accessed from any computer, for free, via www.webapp.condatis.org.uk. Each of the three collaborative case studies has focused on advancing a particular component of Condatis:

1) *Enhancing Sabah's Protected Area network*, Malaysian Borneo, focused on the prioritisation of habitat cells for connectivity in multiple directions;
2) *Scenarios for wildlife corridor restoration in Java*, Indonesia, focused on the inclusion of habitat quality effects for flagship species; and,
3) *Expanding shade cocoa in Western Ghana*, Ghana, focused on robustness to uncertainty when limited ecological data are available.

This report expands on the second case study, exploring the use of Condatis maps in restoration planning within a wildlife corridor, between Mount Halimun and Mount Salak, on the island of Java, Indonesia.

II. Introduction to the Case Study: Mount Halimun Salak National Park

The island of Java is the most densely populated island within the vast Indonesian Archipelago (Fig. 1). Due to its volcanic origin, and ongoing volcanism, it is also one of the most fertile regions of Indonesia, and relies on agricultural productivity to support it burgeoning population. The importance of obtaining as many resources from the land as possible has put pressure on the natural environment. Java contains 33 protected areas (WWF, 2018), ten of which are National Parks, providing some formal protection to the remaining areas of natural/semi-natural habitats that exist on the island. However, the boundaries of the Parks are not always adhered to, and incidences of illegal land use and resource extraction inside mean that protected habitats are not always in a good ecological condition.

Fig. 1 The island of Java in the Indonesian Archipelago, with its Protected Area network highlighted in yellow and Mount Halimun Salak National Park in red. (All maps in this report were created in QGIS Version 2.18.18 and *Bing Aerial* used to create the basemap, unless reported otherwise; the Protected Areas layer was downloaded from Protected Planet, protectedplanet.net/country/ID.)

Mount Halimun Salak National Park, henceforth referred to as TNGHS (*Taman Nasional Gunung Halimun Salak* in Bahasa Indonesia), is one of these landscapes: due to changes in management and the location of the Park boundaries over the last century, many places within the Park require interventions in order to restore the natural habitat types and conserve biodiversity. It is located in West Java (Fig. 1), and covers an area of 87,699 ha (Fig. 2). It has been described as a "flagship protected area" (Wibisono *et al.*, 2018) in part because of its potential to support more than 100 individuals of the critically endangered Javan Leopard, *Panthera pardus melas*.

In 2003, the area of the National Park was extended to include production & protection forest in the peripheral areas. Much of the extension zone was in a degraded state due to human land use and resource extraction. There are estimated to be more than 100,000 people living across 348 villages inside the boundaries of the National Park (pers. comm. Erlan Sodahlan) all of whom seek a viable livelihood. In addition, illegal mining and illegal encroachment of areas within TNGHS create challenges for the people trying to protect and restore the forest habitat within the Park.

In 2004, GHS started a Conservation Kampung Model (CKM) and forest restoration was part of the programme. The CKM was proposed as a way of developing collaborative sustainable landscape management projects within TNGHS, where the villagers could decide on the most appropriate activities for them to promote conservation and sustainable development. Four years later, GHS started to run an economic development programme. These projects involve open and ongoing discussions between TNGHS Staff, stakeholder organisations and members of the communities, to create a restoration plan designed and implemented by the villagers, i.e. those that will ultimately be working on and affected by a restoration project. This programme has proven relatively successful thus far, so much so that Staff working on restoration projects in other National Parks across Indonesia are visiting TNGHS to find out how the CKM works (pers. comm. Erlan Sodahlan).

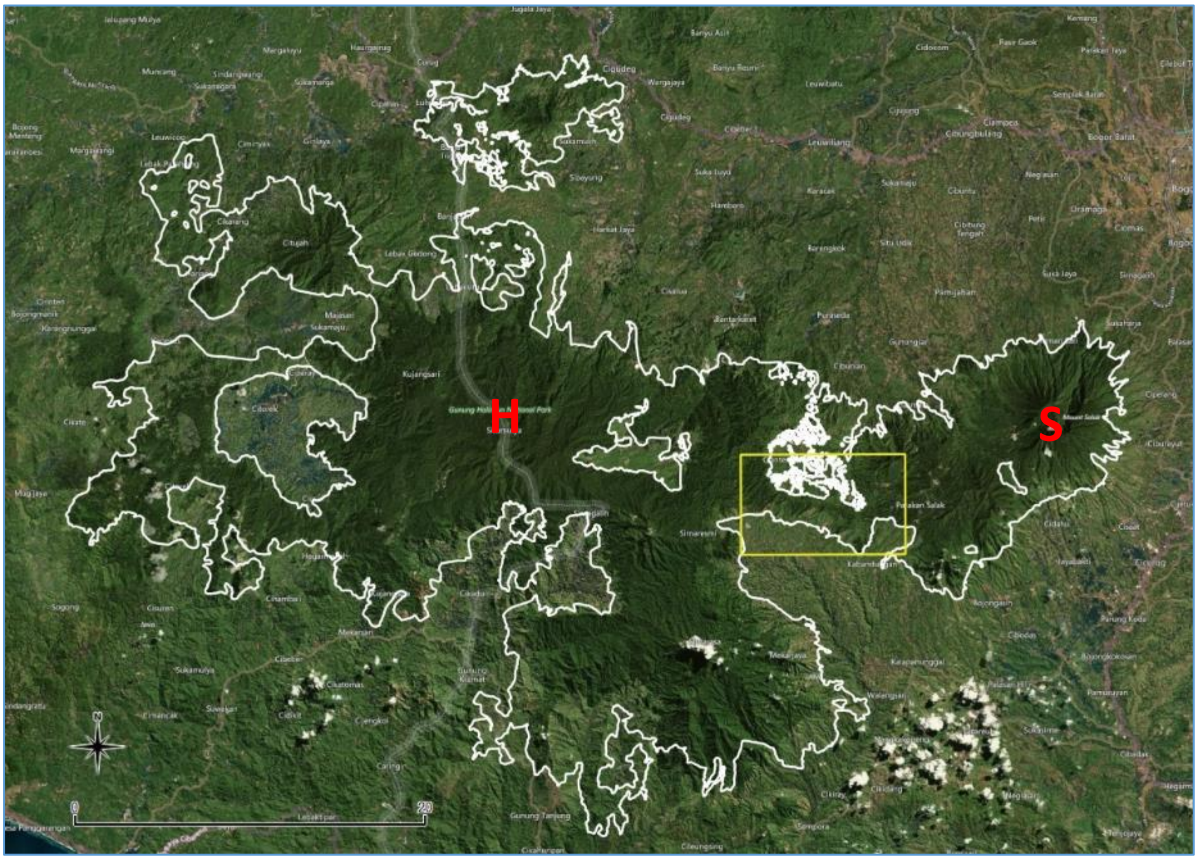


Fig. 2 Mount Halimun Salak National Park (TNGHS) in West Java, outlined in white. The map demonstrates how forest, which would have extended over much of the area shown in the past, does not reach the edges of the Park boundary. The wildlife corridor, on which the Condatis case study focused, is shown in yellow, and the approximate locations of Mount Halimun and Mount Salak marked by **H** and **S**, respectively. (The boundary of TNGHS was downloaded from Protected Planet, protectedplanet.net/country/MY.)

One area of TNGHS that has been a particular focus of restoration efforts has been the wildlife corridor[1] between Mount Halimun and Mount Salak (outlined in yellow, Fig. 2). This is a narrow strip of habitat of huge importance for connecting the much greater area surrounding Mount Halimun with the smaller but higher elevation area around Mount Salak. Years of plantation management within the wildlife corridor zone, in particular of *Agathis* spp. tapped commercially for resin, have created a relatively species poor and homogenous landscape through which the movement of native species is restricted. The Staff of TNGHS have been working with communities living in the proximity of the wildlife corridor to identify locations in which to implement restoration programmes. There are numerous locations where interventions could be started, but only limited resources for this work, thus the Staff must prioritise where to focus their efforts.

This wildlife corridor has been chosen as a case study landscape on which to conduct a Condatis analysis in order to provide information that could help the staff of TNGHS. The aim of this study is to demonstrate how restoration in the corridor could enable movement of threatened species, which can support decisions about the effective areas for restoration.

[1] In this study, a wildlife corridor is used to refer to a strip of land with the purpose of connecting populations in the 'core areas' at either end. To be effective, a wildlife corridor should be more permeable (or less dangerous) to species than the landcover on either side, but it may not all comprise breeding habitat or intact forest.

Based on the data available and on a workshop with some Staff of TNGHS and Professor Prasetyo, at the TNGHS Headquarters in July 2018, we defined the parameters of this Condatis case study (Table 1). Considering the parameters detailed in Table 1 is an important exercise to perform prior to running any analysis in Condatis, and will improve the likelihood of an output proving useful.

Table 1 Key parameters for consideration when designing an analysis in Condatis, and the specific details of those defined for this case study. *Suitability analysis is described in the Methods section below.

What kind of species are you interested in?	**Javan Gibbon** and **Javan Leopard** (endangered species)
What is your source and target?	Source is Mount Halimun; target is Mount Salak
Why do your species need to move between the focal source and target?	For larger total populations, long-term resilience and genetic exchange, perhaps also to avoid isolation as the climate changes.
What constitutes habitat?	Forest, weighted by suitability*
What kind of prioritisation are you performing?	Testing and comparing scenarios for restoration of degraded forest
Who will be interested in the results?	Mount Halimun Salak National Park Authorities & associated parties

III. Methods

A series of *flow* analyses were performed in Condatis, exploring the connectivity of the Mount Halimun-Salak wildlife corridor for two endangered species (Table 1). The *colonisation speed* of a landscape is a measure of how connected a landscape is for the species of interest (Hodgson *et al.*, 2012): a greater colonisation speed represents the presence of a more connected habitat network. Prior to running the analyses, the input parameters were defined and input raster layers generated.

(i) Species parameters

Two species were chosen on which to perform the Condatis analyses: the Javan leopard, *Panthera pardus melas*, and the Javan gibbon, *Hylobates moloch*. These species were chosen because of their iconic and conservation status within TNGHS: critically endangered (Cat Specialist Group, 2018) and endangered (IUCN Red List, 2008), respectively. They were also the species for which there was the most abundant and recent location data, and the most interest in modelling amongst the National Park Staff. The various parameters required for a Condatis analysis were estimated for these two species (Table 2).

Table 2 The characteristics required to perform analyses in Condatis, populated with data for the two chosen species, the Javan gibbon and the Javan leopard. Further information on the variables are provided below.

Condatis variable	**Javan Gibbon (*Hylobates moloch*)**	**Javan Leopard (*Panthera pardus melas*)**
Dispersal distance (DD) (km)	1	4.2
Reproductive rate (RR) (individuals/km^2)	5	1

Habitat raster	*Habitat suitability index*	*Habitat suitability index*
Source/Target raster	Movement between Mount Halimun (Source) & Mount Salak (Target)	
Restoration scenarios	(i) Restoration 2016-2019; (ii) Plantations; (iii) All (see Fig. 6 for further details)	
References	Iskandar, 2006, 2009; Setiawan *et al.*, 2012; Yumarni, 2012	Cat Specialist Group, 2018; Wibisono *et al.*, 2018

Dispersal distances and reproductive rates were calculated through collating information from a variety of different sources (Table 2). Where information on the density of reproductive individuals per km^2 was absent, population density was used as a proxy. For example, the approximate population density of the Javan leopard was reported to be 0.15 individuals per km^2 (Cat Specialist Group, 2018), which is likely higher than the number of reproductive individuals; however Condatis does not yet recognise values less than one, thus a value of one was used. Similarly, where information on the dispersal distance of the species was limited, proxies were used: for example, Wibisono *et al*. (2018) reported that "the known diameter of the largest Javan leopard home range size (was) 13.6 km^2", thus we used the radius of this home range, i.e. 4.2km, as the average dispersal distance of a reproductive individual.

(ii) Raster layer parameters

The raster layers were prepared according to the parameters defined in Table 3. The cell resolution was set to 30m x 30m, as defined by the resolution of the Landsat layer that formed the basis of one component part of the *Habitat Suitability* maps.

Table 3 The parameters of all raster layers used in the Condatis analyses, i.e. Source/Target and Habitat rasters.

Coordinate Reference System (CRS)	Cell resolution	North	East	South	West
EPSG:32748, WGS 84 / UTM zone 48S	30m	9256207.6593	683171.51047	9250537.6593	673811.51047

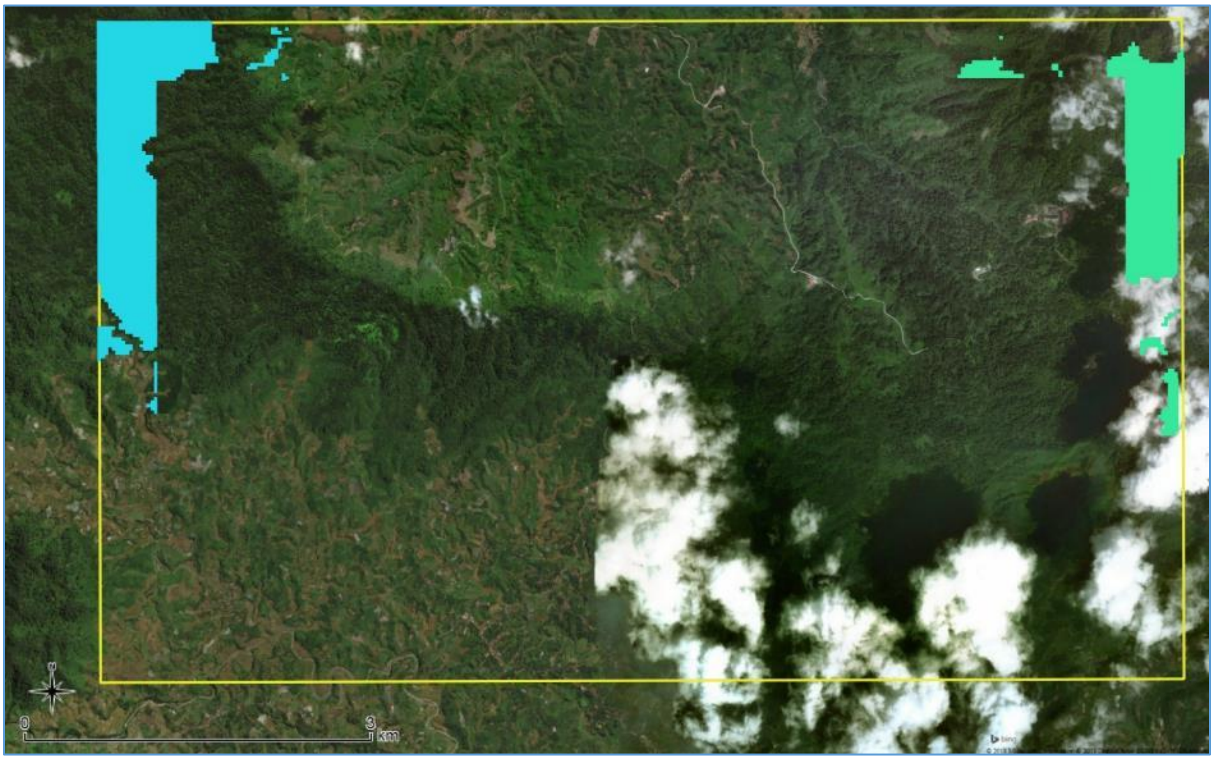


Fig. 3 The boundary of the landscape of interest (yellow), with the raster layer showing the Source (blue) and Target (green).

Source/Target

The *Source* was chosen as Mount Halimun and *Target* as Mount Salak, (note movement is likely to occur in both directions, and Condatis would produce the same results if source and target were switched). Both mountains are large patches of primary forest, critical for the long-term viability of these endangered species. Populations may also find Mount Salak (2,211 m height) more favourable over time, due to climate warming, than the lower Mount Halimun (1,929m height).

A buffer of 0.5km width was created along the edge of the landscape of interest in order to delineate the Source/Target (Fig. 3). Only *Forest* grid cells within these Source/Target buffer zones were then selected to form the Source and Target cells. All Source cells were then assigned a value of 1, and all Target cells 2, in order for Condatis to differentiate between the two features.

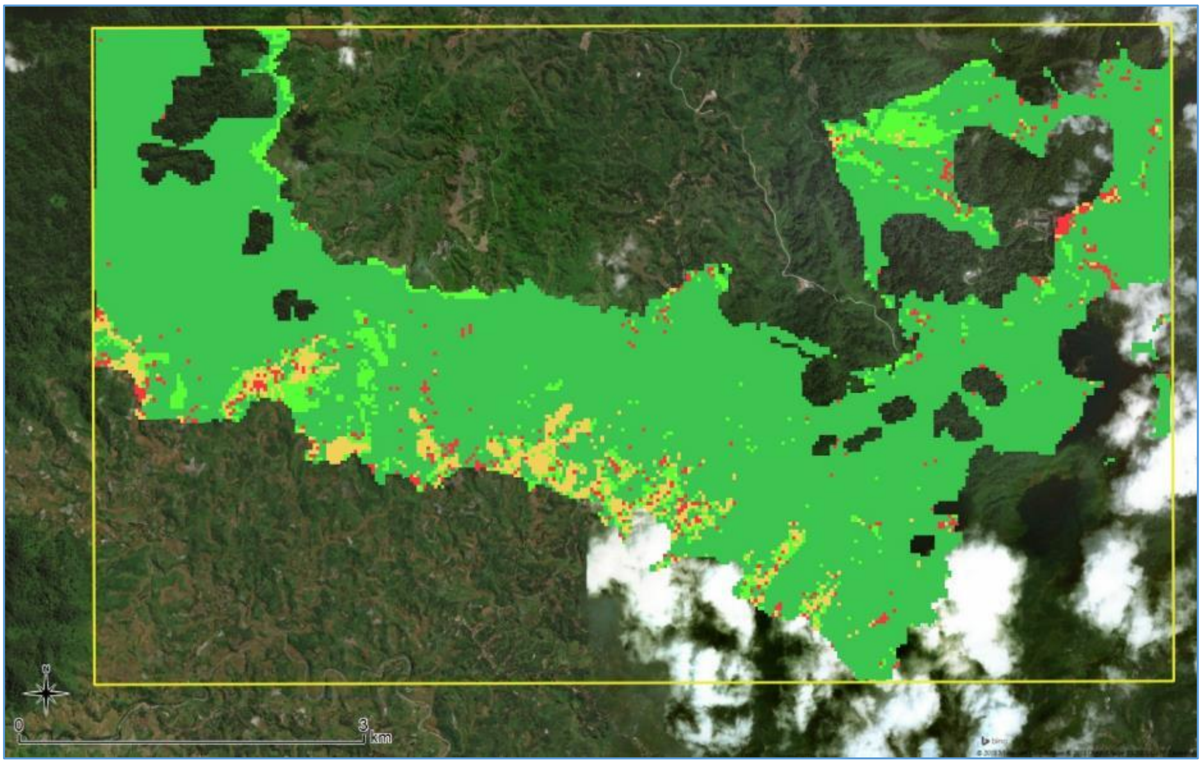


Fig. 4 The Landsat-derived land cover layer for the landscape of interest (yellow). Land cover types include: Forest (dark green), Scrub (light green), Agriculture (orange), Settlement (red) and Cloud & Shadow (black).

Habitat parameters

A multi-component *Habitat Suitability* layer was used as the habitat raster input file in the Condatis modelling exercise. For each of the Javan Gibbon (Fig. 5) and the Javan Leopard (Fig. 6a), a habitat suitability raster file was generated, comprising eight different layers (Table 4), combined using Maxent (Phillips *et al.*, 2018), by Professor Lilik Budi Prasetyo and his students. Each layer represents a physical characteristic of the landscape, which influences the probability of finding the Javan Gibbon or Leopard. The *Presence points* layer for each species illustrates where sightings of the individuals, and or artefacts, such as calls, faeces, remains of a carcass or fruit, or trail marks, have been observed. The Maxent analysis produced a probability occurrence map of the species, which represents the habitat suitability ranging from 0 to 1, in order for it to be recognised by Condatis.

Table 4 The different component layers of the *Habitat Suitability* layer.

Component layers	Source of data/Analytical method
Land Cover	Landsat OLI 8*
Air Temperature 2017	Landsat OLI 8
Elevation	DEM ASTER/GDEM[ϕ]
Slope	DEM ASTER/GDEM
Distance from river	Euclidean Distance
Distance from road	Euclidean Distance
Distance from Settlement	Euclidean Distance
Presence points of Javan Gibbon (127 points)	Secondary data†
Presence points of Javan Leopard (26 points)	Secondary data

*Landsat Operational Land Imager (OLI) 8: https://landsat.gsfc.nasa.gov/operational-land-imager-oli/
ᶲDigital Elevation Model (DEM) Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)/Global Digital Elevation Map (GDEM): https://asterweb.jpl.nasa.gov/gdem.asp
†From TNGHS and additional publications

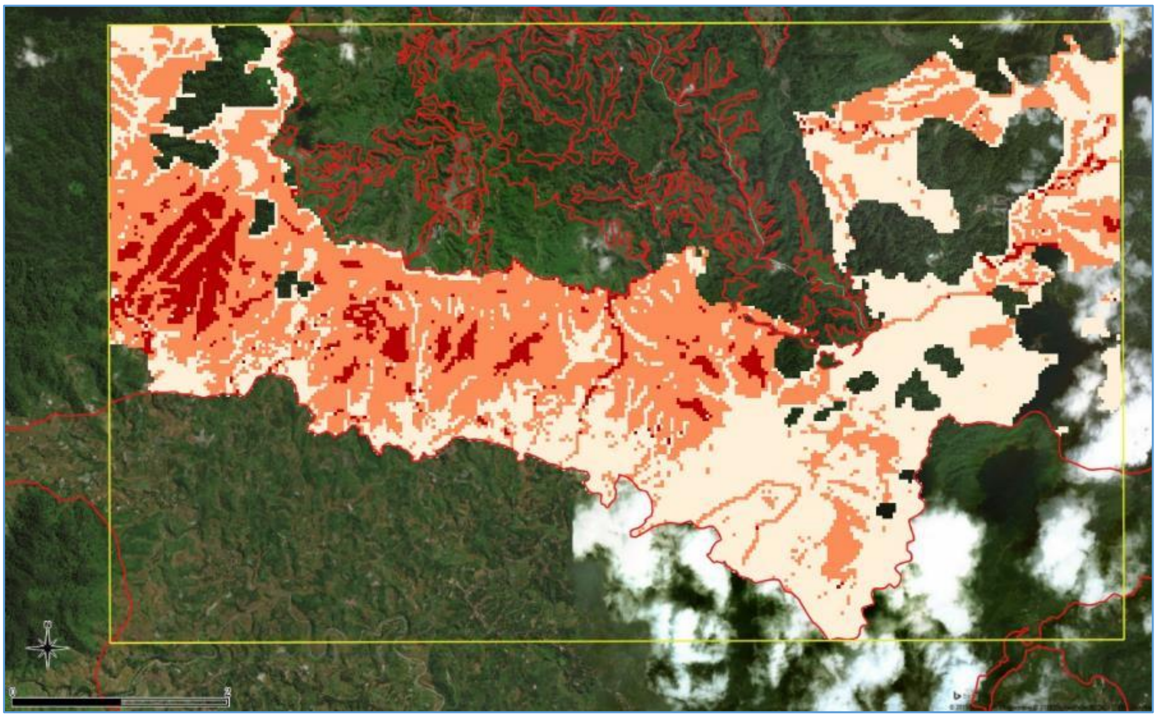


Fig. 5 The Habitat Suitability layer for the Javan Gibbon, used in this study to represent a Business as Usual (BAU) scenario. Three levels of relative suitability are shown: cream depicts low suitability, orange medium suitability and red illustrates pixels with a high habitat suitability for the Javan Gibbon.

Restoration scenarios

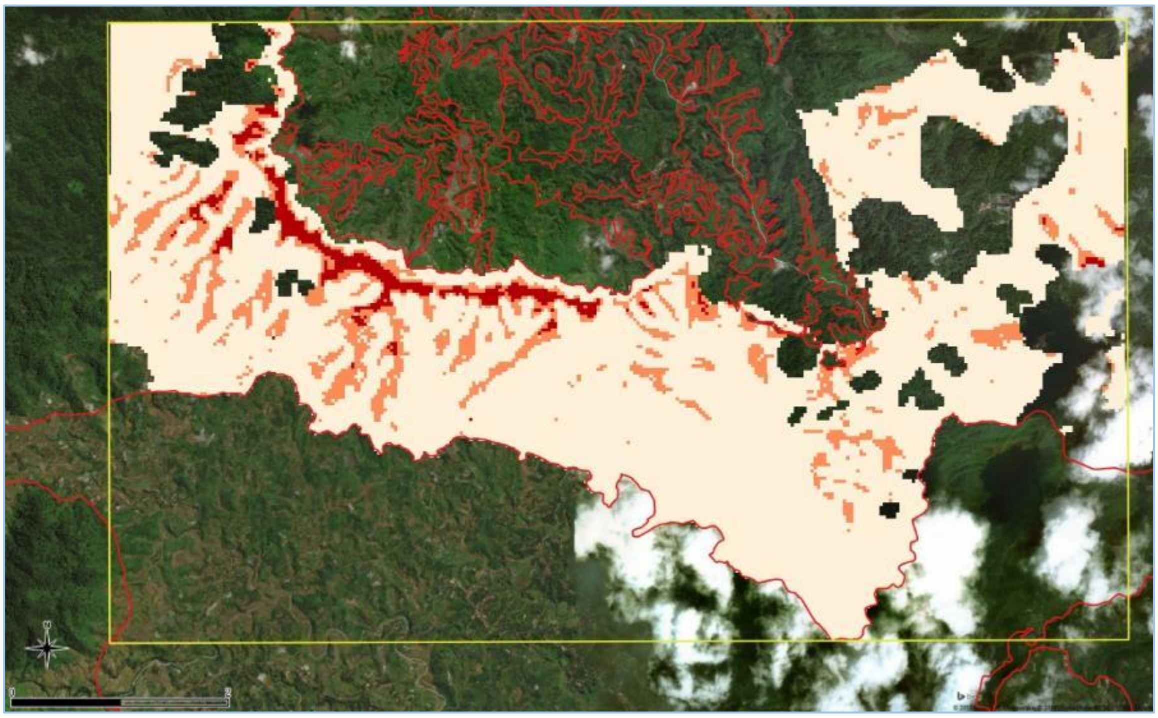
Three restoration scenarios were developed to illustrate the potential changes in connectivity of the landscape if non-forested land covers were restored to forest (Table 5, Fig. 6). Polygons of broad categories of land cover for TNGHS for 2017, provided by National Park Staff, were used to classify the land covers included in each restoration scenario. For all restoration scenarios, each grid cell proposed for restoration was given a value of 1, i.e. the maximum score for habitat value, equivalent to the cell containing 100% suitable habitat. This is a very unlikely scenario, but due to a lack of alternative data from which to create habitat suitability maps for each restoration scenario, this simplified approach has been adopted. The realisation of the *All* scenario in practice is highly unlikely but used here to provide an extreme example of how restoration can affect the colonisation speed of a landscape.

Table 5 Restoration scenarios developed to demonstrate the potential impacts of changes in land cover to the colonisation speed of the landscape.

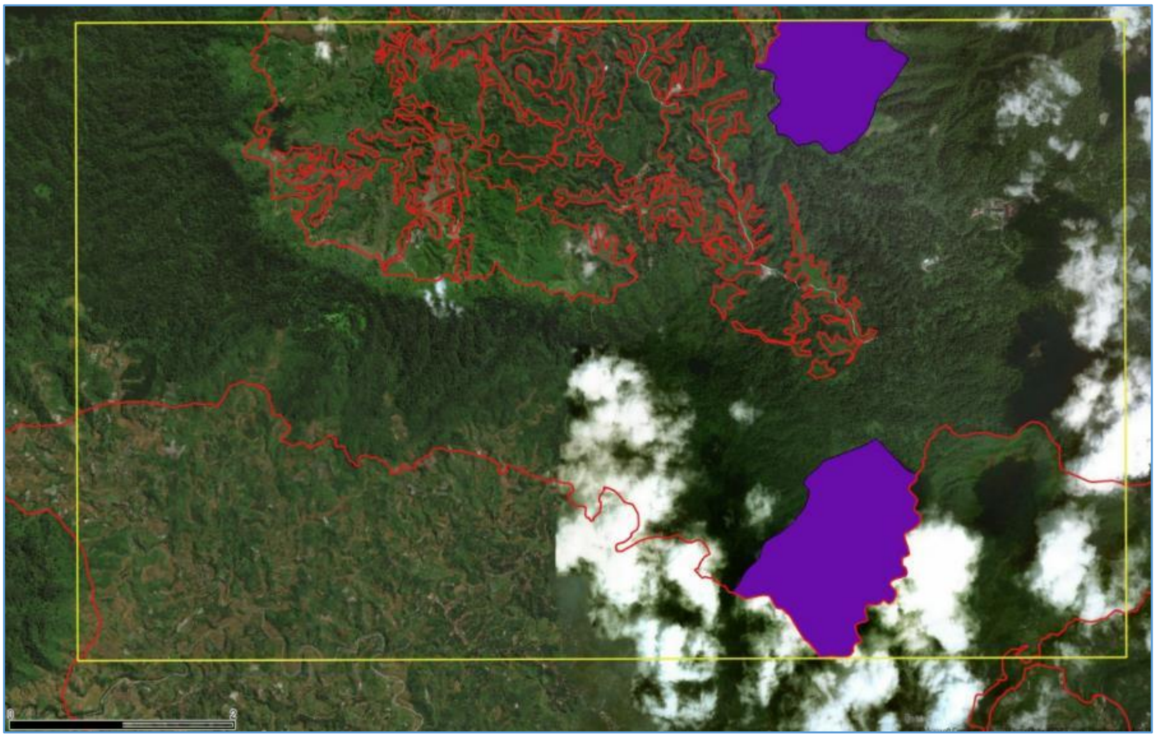
Restoration scenario	Land cover change	Reference Figure
Business as Usual (BAU)	Current land cover, i.e. Habitat Suitability maps	6A
Restoration 2016 – 2019	Areas in the north and south of the corridor, within a restoration programme running from 2016 to 2019, are fully restored to native forest	6B

Plantations	All plantation areas within the corridor are restored to native forest	6C
All	All land covers within the corridor are restored to native forest	6D

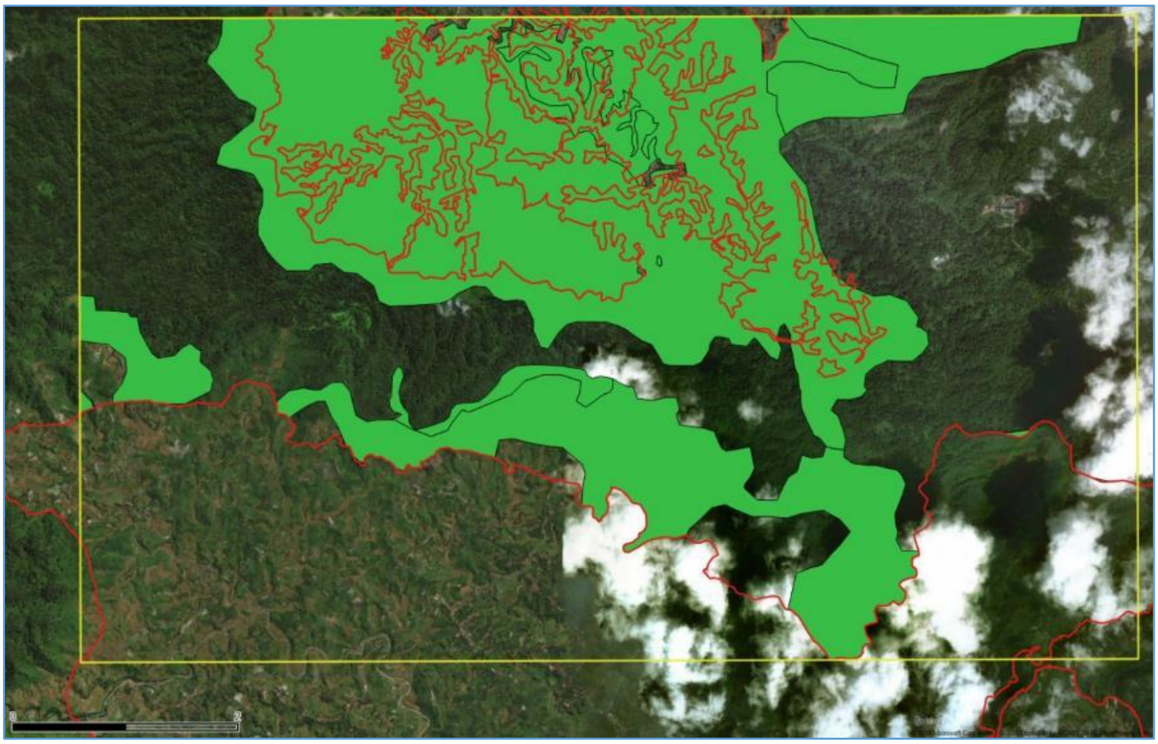
(A) Business as Usual – Javan Leopard



(B) Restoration 2016-2019



(C) Plantation



(D) All

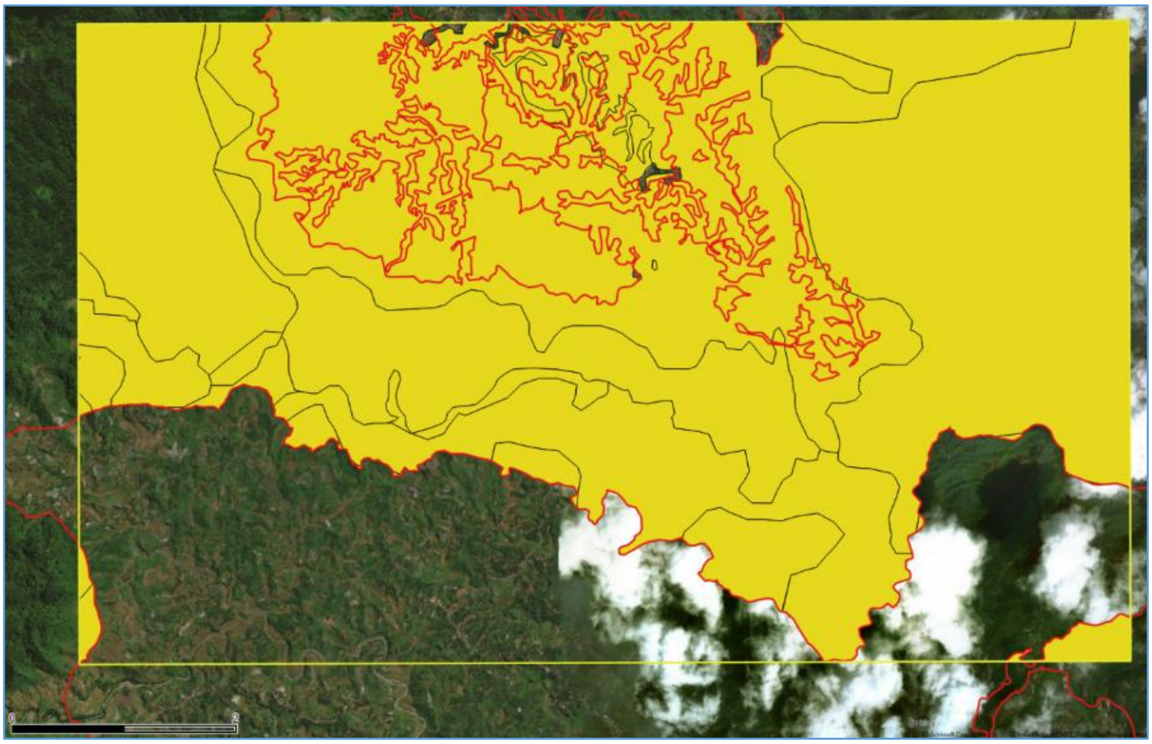


Fig. 6 The three restoration scenarios, and Business as Usual (BAU) included for reference: (A) *BAU* for the Javan Gibbon, representing the current situation as dictated by the *Habitat Suitability* map; (B) *Restoration 2016-2019*, where the two areas currently within one of the National Park's restoration programmes (purple shapes) are fully restored to native forest; (c) *Plantations*, where the areas that are currently occupied by remnant trees from past plantations (green shapes) are restored to native forest, and (D) *All*, where all of the land cover classes within the landscape of interest (yellow shapes) are restored to native forest. (These later

scenarios are meant as illustrative only and do not represent planned, or likely even feasible restoration scenarios.)

IV. Condatis Results

Here are reported the main outputs from the Condatis analyses for each species. A Condatis analysis computes a *flow value per cell*. Flow is a measure assigned to each habitat cell that gives an indication of the relative number of individuals moving through that cell that will go on to colonise the target (strictly speaking, their descendants will colonise the target). The larger the flow value of a habitat cell, the more important that cell is for connectivity between the source and the target. Flow of individuals only occurs through habitat cells, defined by the uploaded habitat map.

Another output of Condatis is the *colonisation speed* of the landscape. This is a measure of overall or total flow, i.e. successful movement of a species/taxonomic group from the source to the target. The faster the speed, the shorter the time taken to reach the target (specifically for the first individual to arrive at any target cell, not necessarily colonisation of the whole target area or movement of the whole population). If the landscape configuration changes and/or the species being modelled changes, the speed will change. For example, if a species has a shorter dispersal distance, or produces fewer individuals per km^2 per generation, all movement through the landscape will be slower. Landscape configuration can also have a large impact on speed (see Hodgson et al., 2016 for more information on this). Speed is a relative measure that can be compared across scenarios computed by Condatis. Thus, it is a useful output in this case study as it enables us to compare the influence of different restoration scenarios on the colonisation speed of the landscape, i.e. changes in connectivity resulting from changes forest cover.

(i) Javan Gibbon

Under a Business as Usual (BAU scenario) for the Javan Gibbon, the colonisation speed of the landscape is 14.988 (Table 6), and areas of higher flow seen in the western side of the corridor (Fig. 7a). When the different restoration scenarios are explored for their impact on colonisation speed, the connectivity of the landscape changes significantly (Table 6), i.e. the greater the area that is restored, the greater the colonisation speed and thus less time taken for the species of interest to cross the landscape from source to target.

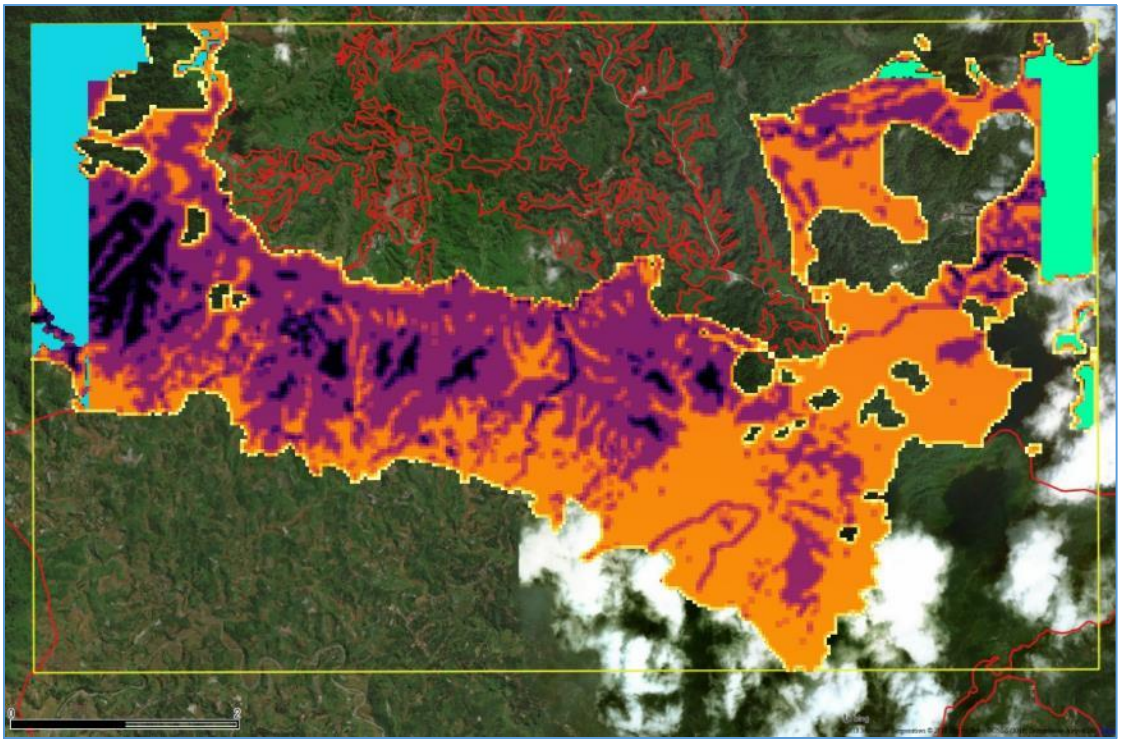


Fig. 7a The pattern of flow across the wildlife corridor under the BAU scenario for the Javan Gibbon, as represented by a flow map generated in Condatis, using the input parameters outlined in Table 2. The flow, presented geospatially within this figure, is represented on a cream to black colour scale (Fig. 7b).

Fig. 7b The colour scale illustrating the relative flow through each grid cell within the landscape. Cells with high flow, i.e. that are of the greatest importance for enabling individuals of the species of interest to move through the landscape, are shown in black, and cells with the lowest flow, and thus provide little connectivity between the source and the target, are shown in cream.

Table 6 The change in colonisation speed under different restoration scenarios (numbers rounded to 3 d.p.).

Species of interest	Restoration Scenarios			
	Business as Usual	Restoration 2016-2019	Plantations	All
Javan Gibbon	14.988	18.119	40.937	61.145
Javan Leopard	0.158	0.205	0.536	0.855

(ii) Javan Leopard

Under a Business as Usual (BAU scenario), the colonisation speed of the landscape for the Javan Leopard is 0.855 (Table 6), and areas of higher flow are mostly restricted to a linear route along the northern edge in the western half of the corridor (Fig. 8). When the different restoration scenarios are explored for their impact on colonisation speed, the connectivity of the landscape changes significantly (Table 6, Fig. 9), over five-fold when comparing the *BAU* to the *All* restoration scenario.

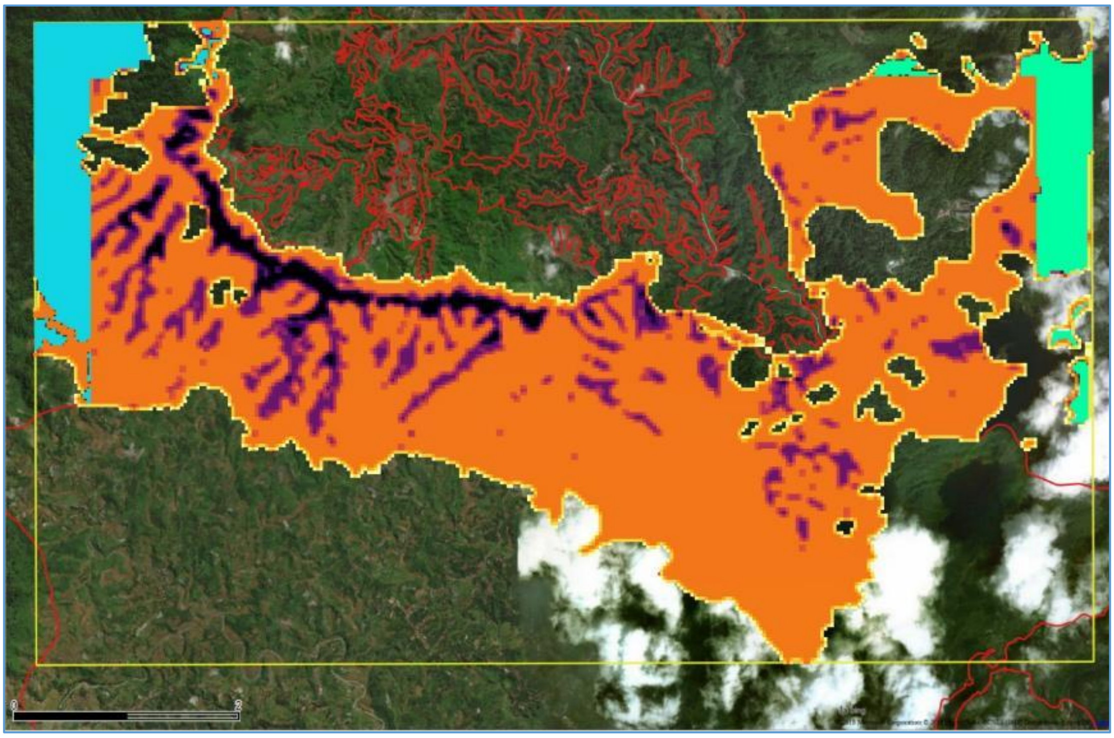
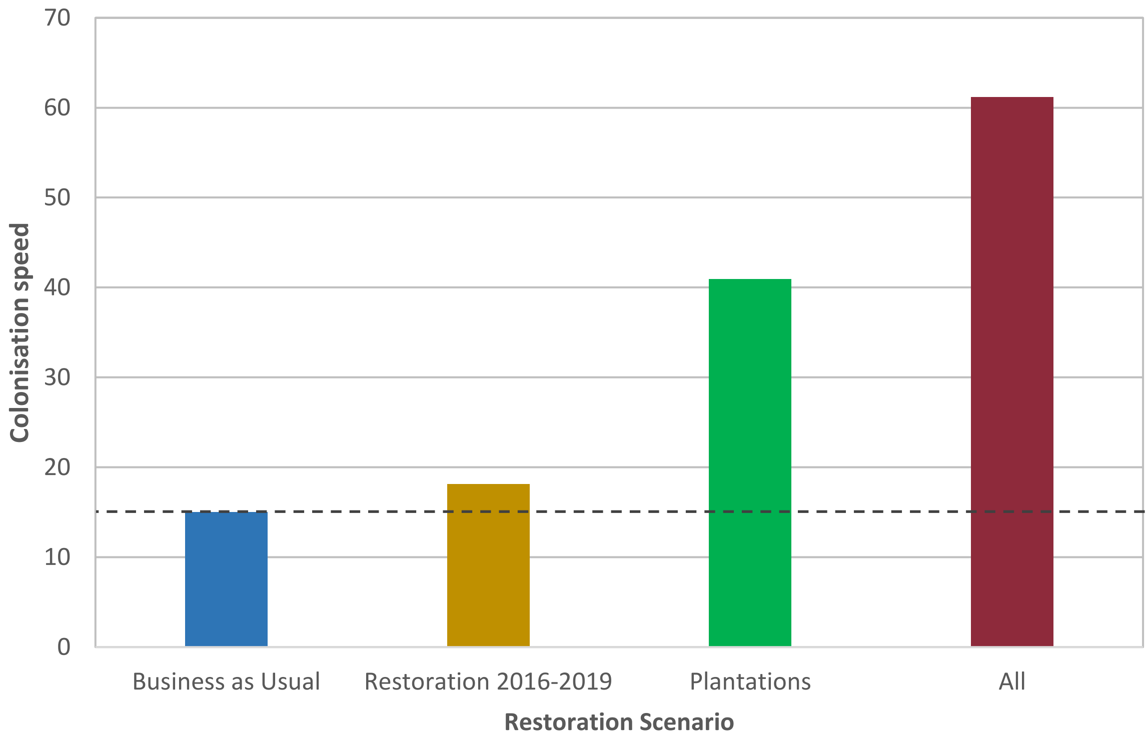


Fig. 8 The pattern of flow across the wildlife corridor under the BAU scenario for the Javan Leopard, as represented by a flow map generated in Condatis, using the input parameters outlined in Table 2. See Fig. 7b for the colour scale.

(A) Javan Gibbon



(B) Javan Leopard

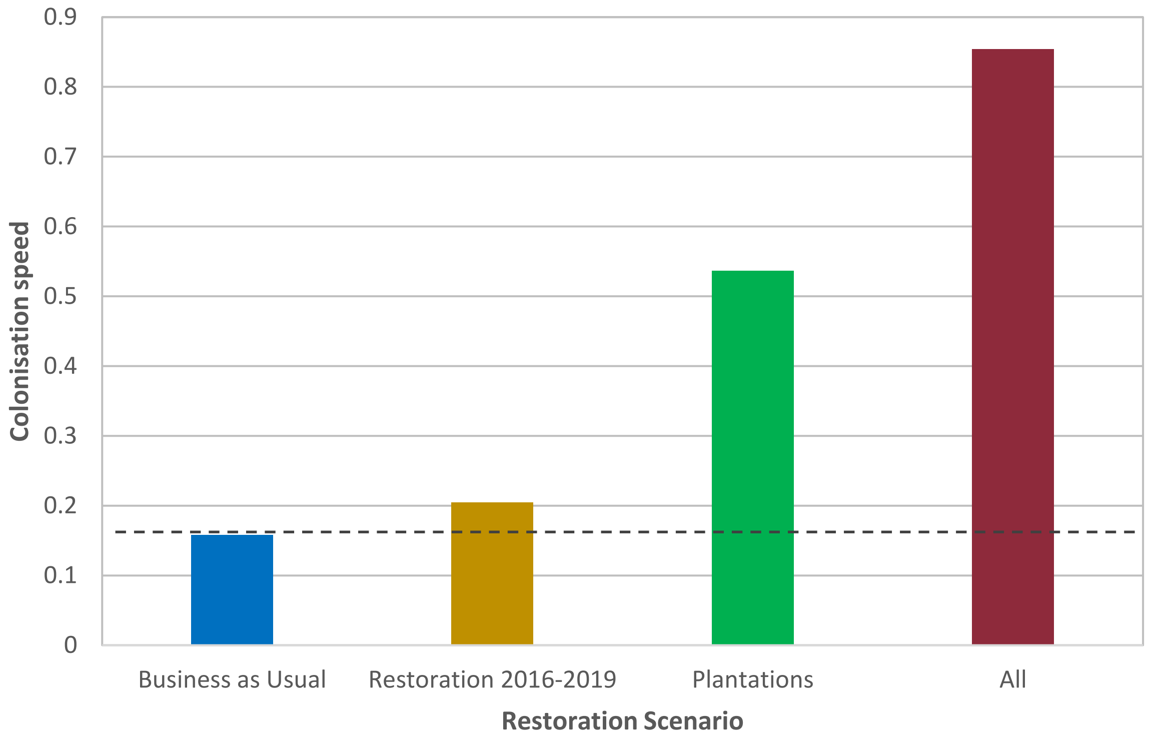


Fig. 9 Graphical illustrations of the impact of different restoration scenarios on the colonisation speed of the landscape for: (A) the Javan Gibbon and (B) the Javan Leopard. A horizontal dashed line has been included to indicate the colonisation speed of the BAU scenario.

When exploring the increase in landscape connectivity offered by the three different restoration scenarios compared to BAU for each species, results suggest that the colonisation speed increases more dramatically for the Javan Leopard than for the Javan Gibbon (Table 7).

Table 7 The percentage increase in connectivity of the landscape of interest for each species under the three restoration scenarios, compared to the BAU habitat suitability configuration, as computed by Condatis flow analyses. (Percentage values have been rounded to 1 d.p.)

Species of interest	**Increase in colonisation speed from BAU**		
	Restoration 2016-2019	Plantations	All
Javan Gibbon	20.9%	173.1%	308.0%
Javan Leopard	29.7%	239.3%	440.5%

V. Discussion

Results show that there is a difference in both the pattern (Figs. 7a and 8) and speed of flow (Table 6) within the TNGHS wildlife corridor between the two species. The connectivity of the landscape under a BAU scenario, based on the habitat suitability map, is over 100 times greater for the Javan Gibbon compared to the Javan Leopard, i.e. 14.988 and 0.158, respectively (Table 6). Though the dispersal distance of the leopard is greater than that of the gibbon, a greater area of the wildlife corridor represents suitable habitat for the gibbon (Fig. 5) compared to the leopard (Fig. 6a), in sufficiently connected patches, to enable movement between the source and target. The gibbon also has a five-fold greater reproductive rate than the leopard, providing more potential dispersers and subsequent colonists in each generation, which will result in more opportunities for movement across the landscape. These results illustrate the importance of considering multiple parameters when modelling how connected a landscape is for a population: notably the life history traits of the species of interest and the physical characteristics of the landscape.

When exploring the impact of restoring different patches of habitat on the connectivity of the landscape for the two species, the increases in colonisation speed follow similar trends (Figs. 9A and B). In general, the greater the area of land restored to forest, following the progression from *Restoration 2016-2019* to *Plantation* to *All* restoration scenarios, the greater the increase in the colonisation speed of the landscape (Table 6), as expected. However, the increase in the colonisation speed of the landscape from the BAU habitat configuration to each restoration scenario, was notably greater for the Javan Leopard compared to the Javan Gibbon (Table 7). This suggests that any interventions to restore forest will contribute more to enhancing the connectivity of this landscape for the leopard in comparison to the gibbon. Given the critically endangered status of the Javan Leopard, this result lends further support for restoration programmes in this wildlife corridor, even a programme involving the least area of land, i.e. *Restoration 2016-2019*. Under this scenario, there is a >20% increase in connectivity, demonstrating that restoring these relatively small and marginal patches, along the edges of the main wildlife corridor (Fig. 6B), will still make a valuable contribution to enhancing the connectivity of the landscape for both species.

The flow maps for each species produced by Condatis can be used to explore priority habitat patches that are important for movement for both species. In any conservation programme, the resources available for restoration activities are often limited (the TNGHS case being no exception), thus it is important to maximise the effectiveness of interventions whilst minimising the inputs, where possible. Through overlaying flow maps for the Javan Gibbon and Javan Leopard, areas in the wildlife corridor that are important for providing connectivity for both can be identified, for example the linear band of habitat along the north west edge of the corridor (Fig. 10). This band is at somewhat higher altitude than the rest of the corridor. It also has higher habitat suitability according to the Maxent analysis for both species. More detailed inspection of the relationships found by Maxent could suggest the reasons for this high suitability (e.g. whether due to altitude or distance from roads). A general policy approach could be to conserve these areas with high suitability and high flow, to prevent their deterioration, while restoring areas near them so that they are also ultimately of high suitability if possible.

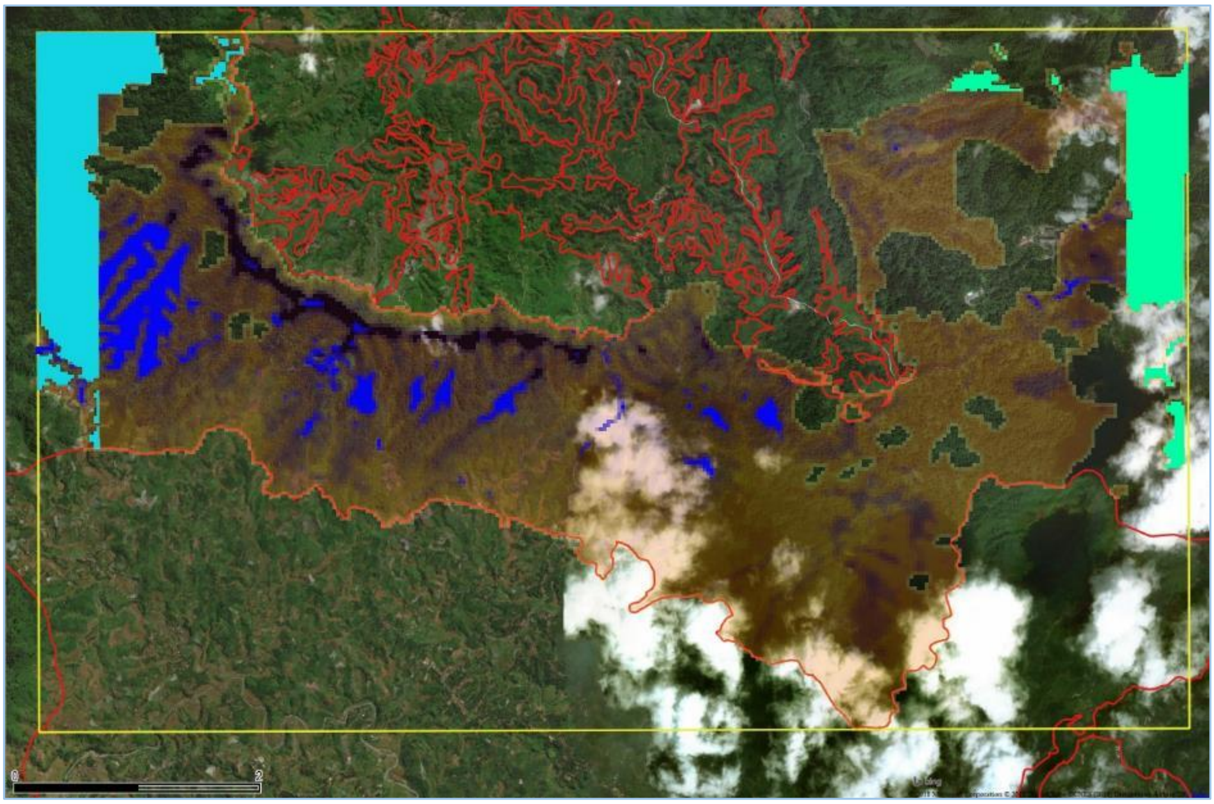


Fig. 10 Condatis flow maps for the Javan Gibbon (blue) and Javan Leopard (black) overlayed in QGIS, with reduced transparency of the lower flow values, in order to identify the priority patches of habitat for preserving connectivity for both species.

Managers could influence some of the bio-geographical variables that affect both habitat suitability and the permeability of the corridor, but not others. Of particular importance for the Javan Leopard may be the accessibility of the landscape for people: the Cat Specialist Group (2018) reports that one of the main threats to the persistence of the leopard is poaching, and this factor may be correlated with distance from roads/settlements as used in the Maxent analysis. Thus creating corridors of habitat, with limited human access or presence, may increase the survival chances of this species. However, as ever in conservation there is a balance, or indeed a compromise to be made, and the more accessible, human-modified areas within the landscape may provide "vital extensions" for certain populations (Wibisono *et al*., 2018).

VI. Policy Relevance

The maps produced through Condatis provide information on the likely pathways two threatened species will use to move between Mount Halimun and Mount Salak. This information may be used to design where forest restoration projects could be effective in terms of biodiversity conservation. In the results so far, it is striking that flow is so closely correlated with habitat quality: this suggests that quality of habitat will be more of a crucial factor for the success of restoration than will its precise location.

The planning of each forest restoration project at TNGHS requires careful consideration of the ecological, social and economic characteristics of the different potential sites, in order to design a programme that will be most successful in the long term. Success depends on ecological factors, for example the survival of introduced tree seedlings, natural forest recovery, quality of the habitat restored for key species; and of key consideration, socio-economic factors, including the method by which communities living in a proposed restoration locality acquire their income, for example forest resources-based or through agricultural produce. The National Park Staff, working in conjunction with various other stakeholder organisations, such as Kehati, must design restoration programmes in close collaboration with communities in order that anything implemented be successful. Whenever further maps of practically feasible restoration areas become available, these could be tested for their effect on colonisation speed using Condatis in the same way as we have tested the 2016-2019 areas above. This will provide ecological support for the restoration interventions, and can help communities to compare different options as part of an interactive mapping process. A more holistic restoration prioritisation scheme in TNGHS could ultimately be achieved by combining Condatis analyses with on-the-ground knowledge.

VII. Limitations

This study was performed to illustrate the outputs that Condatis is capable of producing for a variety of landscapes. We were particularly interested in exploring how two different species experienced different connectivity because of different relative habitat suitability. While this has been achieved, the landscape and scenarios of this case study do not fit Condatis' assumptions in some ways: principally, the wildlife corridor is only approximately 8km at its widest stretch, so crossing it does not necessitate multi-generational dispersal for species with relatively long dispersal distances, such as the Javan Leopard. Another limitation of this study was that the data on which to develop restoration scenarios was limited: ideally habitat suitability maps would be available for the whole landscape within the area of interest rather than just the restricted corridor landscape (for example Fig. 6a). Also, if possible we should have predicted a realistic habitat suitability for the restored areas, rather than assuming they could achieve maximum suitability regardless of their other biogeographical attributes. With more extensive spatial data on habitat suitability for the variety of different species of conservation interest, and within the broader landscapes in which restoration is feasible, Condatis could provide more informative maps of use in the long-term sustainable management of TNGHS.

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