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A practical novel assessment tool for the socio-ecological condition of Protected Areas: The Protection Level Index (PLI)

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ABSTRACT

Protected Area (PA) managers and policy makers need to determine and demonstrate the effectiveness of PA management and keep track of the conservation status in ways that are practical, scientifically sound and comparable among PAs in various terrestrial and aquatic environments. As most existing methods for measuring the managerial efficiency of PAs are restricted to specific elements of the management or a limited number of detailed environmental aspects, often without the participation of practitioners, we aim for a generally applicable method developed in close cooperation with PA managers; the Protection Level Index (PLI). PLI includes ecological, socio-economic, as well as managerial factors, and consists of twelve variables that together describe the state of a PA. Seven of those are derived from interviews with PA managers, and five of them are derived from GIS analyses. Data were obtained during face-to-face interviews with PA managers using a fixed protocol, thereby introducing a new way of incorporating the perception of the PA managers. PLI was tested in seven different PAs across Europe. The lowest final PLI score was for the Island Network of Protected Areas in La Palma and the highest final PLI score was for the Kalkalpen National Park. PLI is wider applicable than other related methods and more cost-effective. Therefore PLI can be used on a yearly basis to keep track of the progress of management activities and conservation status within and among (networks of) PAs.

1. Introduction

Protected Areas (PAs) play a key role in the conservation of natural structures, functions and processes, maintaining species and habitat diversity, delivering a variety of Ecosystem Services or protecting areas of specific interest (Liu et al., 2001; Parrish et al., 2003; Brooks et al., 2004; Rodrigues et al., 2004; Chape et al., 2005; Campos & Nepstad, 2006; Coad et al., 2008; Dudley, 2008; Wild & McLeod, 2008; Butchart et al., 2010; Cardelús et al., 2013; Scull et al., 2017). PAs have even been considered as the only hope we have of stopping many threatened or endemic species from becoming extinct (Dudley et al., 2013).

Protecting places for means of conservation has already been a tradition for many centuries. From 322 BCE to 187 BCE, the Mauryas protected tigers and elephants (Rangajaran, 2005), and in 118 CE the Roman Emperor Hadrian established rules to protect the mountains of Lebanon for the cedar trees used for ship building (McNeill, 2007; Rich, 2013). The first 'modern' PAs were Yosemite National Park, founded in 1864, and Yellowstone National Park, founded in 1872 as "a public park or pleasuring ground for the benefit and enjoyment of the people" (Bishop, 2004).

Different types of PAs were set up worldwide during the past 150 years (Bishop, 2004) although for different reasons. In North America, PAs were set up to protect dramatic and sublime scenery, in Africa to maintain elite hunting traditions, and in Europe to protect the land- and seascape (Adams and McShane, 1996; Draper et al., 2004; Phillips, 2007; Hummel et al., 2019). However, with time the focus shifted towards preventing loss of natural habitats and species due to human activities. Still, a large range of conservation goals exist and for every PA

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there are unique motives for designation. This unique character makes it difficult to unequivocally define a PA.

A rather general definition of a PA, to include as many types of PAs as possible, used by the Convention on Biodiversity (CBD. 1992) is: A geographically defined area which is designated or regulated and managed to achieve specific conservation objectives. As such, in 2017, PAs covered in total about 15% of the land surface of the planet and about 7% of the marine environment (ProtectedPlanet, 2017).

As more and more PAs were established around the world with different management and protection objectives, for means of clarification and standardisation, the International Union for the Conservation of Nature (IUCN) developed a categorising system for PAs in 1933 (Holdgate, 2014). In 1994 IUCN defined six categories for classifying PAs according to their management objectives: Ia – Strict nature reserve, Ib – Wilderness area, II – National park, III – Natural Monument or feature, IV – Habitat/species management area, V – Protected landscape or seascape, and VI – Protected areas with sustainable use of natural resources (Dudley et al., 2013).

The designation of a certain IUCN category to a PA however does not guarantee an effective insight in the actual (environmental or socio-economic) status of a PA. The reason for this is that IUCN categories are mainly based on the PA management strategy on paper, and not on the actual effects of that strategy in the field. Consequently, so called "paper parks" can occur, PAs that despite a good management plan on paper have little or no actual effective protection in the field, due to absent or ineffective management (Brandon et al., 1998; Blom et al., 2004, Bonham et al., 2008).

In the last decades, many efforts have been made to develop PA management effectiveness methodologies (Blanco and Gabaldon, 1992; Courrau, 1999; Dudley et al., 1999; Hockings et al., 2000; Cifuentes et al., 2000; Ervin, 2003a; Stolton et al., 2003; Blom et al., 2004; BirdLife International, 2006; Leroux et al., 2010; Mc Arthur et al., 2010). These methodologies mainly focus on managerial issues and only a few contextual environmental and socio-economic issues. By not paying enough attention to the effects in the field, they may cause a threat to the management. Moreover, the majority of these methods are often not generally applicable (Hockings & Phillips, 1999; Pomeroy et al., 2004), and may require quite some financial or personnel effort (Stoll-Kleemann, 2010).

The more recent publications show an even stronger restriction to a limited number of detailed variables, mostly abstracted from databases, with a managerial focus (Eklund et al., 2019; Armitage et al., 2020), or environmental focus (Hoffmann et al., 2017; Mikoláš et al., 2017; Friedrichs et al., 2018; Brown et al., 2019; Riggio et al., 2019; Cazalis et al., 2020; Negret et al., 2020; Terraube et al., 2020; Wolf et al., 2021); or socio-economic emphasis (Bennett et al., 2019; Cazalis & Prévot, 2019; Jones et al., 2020).

As PA managers and policy makers are under increasing pressure to determine the effectiveness of their PA in ways that are practical, scientifically sound and comparable among different PAs (Parrish et al., 2003), we aimed to develop a new index to overcome the before mentioned obstacles, the Protection Level Index (PLI). As such, PLI allows for a cost effective, multidisciplinary, and practical assessment of the degree of protection in any type of PA worldwide from a managerial as well as an environmental and socio-economic point of view.

PLI assesses the level of protection in a PA by measuring managerial, socio-economic as well as environmental factors. It consists of a set of twelve sub-indices. Next to the inclusion of the major disciplinary approaches, one of the innovative elements of PLI is that it includes the perception of the PA manager to put numerical quantifications of some parameters into context.

2. Materials and methods

2.1. PLI sub-indices

All twelve sub-indices that together form the final PLI score have been selected in such a way that they allow for a quick and easy assessment of the degree of protection in a PA. PLI sub-indices were designed and calculated so that a maximum score of 1 is obtained in the case of a desirable situation (high level of protection) and a minimum score of 0 in case of an undesirable situation (low level of protection).

The twelve socio-economic and environmental sub-indices (Table 1) are derived from the variables that have been previously identified in the EcoPotential project in which >120 PA managers, rangers and scientists, of 26 PAs in and around Europe, have been interviewed (Hummel et al., 2018).

2.1.1. Illegal activities

Monitoring threats to PAs is important for effective biodiversity conservation (Schulze et al. 2018). As Geldmann et al. (2019) indicated, establishing PAs without ensuring an appropriate mechanism and resources to reduce human pressures can lead to negative effects. One of the strongest human pressures, i.e. illegal activities, should therefore be inventoried.

The Illegal Activities sub-index is the average extent to which a set of illegal activities take place in a PA (Table 2).

The extent to which an illegal activity takes place as indicated by the PA management, is divided into 6 categories (Table 3). In case an activity from the list is not regarded as illegal by the PA management, it is disregarded from the analysis (i.e. no value, and excluded in the calculation of the average for that specific PA). The Illegal Activities sub-index, I_i, reflects the score (sum of the individual scores, A_k) as a fraction of the maximum score:

$$I_i = \frac{1}{n}\sum_{k=1}^{n} A_k$$

where n represents the number of activities regarded as illegal (i.e. the maximum possible score), and A_k is the individual score of k^{th} illegal activity (Table 3).

2.1.2. Enforcement employees

The score for the Enforcement Employees sub-index is based on the average amount of square kilometres to be patrolled by one enforcement employee (Table 4), and the PA-managers perception of the number of enforcement employees (Table 5). The index is the sum of both scores.

Table 1
List of the 12 sub-indices used in PLI, along with abbreviations used in formulas and graphs, and whether they are derived from the PLI interview or GIS analyses.

Index (sub-indices of PLI)	Abbreviation in formulas	Abbreviation in graphs	Derived from
Illegal Activities	I_i	IlAR	Interview
Enforcement Employees	I_e	Enfo	Interview
Controlled Visitor Access	I_{cva}	CoVA	Interview
Funding	I_f	Fund	Interview
Corruption Regulations	I_{cr}	CoRe	Interview
Biodiversity	I_b	Biod	Interview
Management Objectives	I_{mo}	ManO	Interview
Edge Effects	I_{ee}	EdgE	GIS
Naturalness	I_n	Natu	GIS
Light Pollution	I_{lp}	LiPo	GIS
Fragmentation	I_{frag}	Frag	GIS
Expandability	I_{exp}	Expa	GIS

Table 2
List of possible illegal activities in a PA used in PLI.

1.	Agriculture/Aquaculture
2.	Commercial extraction of wild biological resources
3.	Non-commercial extraction of biological resources
4.	Building infrastructure
5.	Recreation
6.	Poaching
7.	Extraction of non-renewable natural resources
8.	Drone flights
9.	Motorised access
10.	Littering
11.	Vandalism

Table 3
Categories and scoring of the different illegal activities (A_k) as indicated by the PA management.

Extent to which an illegal activity takes place	Score (A_k)
Does not take place	1.00
Takes place to a *negligible* extent	0.80
Takes place to a *small* extent	0.60
Takes place to a *moderate* extent	0.40
Takes place to a *large* extend	0.20
Takes place to a *very large* extent	0.00

Table 4
Scoring of the enforcement density based on the average amount of square kilometres to be patrolled by 1 employee (E_1).

Enforcement density	Score (E_1)
1–12.5 km^2	0.2
12.5–25 km^2	0.3
26–50 km^2	0.4
51–100 km^2	0.2
≥101 km^2	0.0

Table 5
Scoring of the perception of PA-managers of the number of enforcement employees needed to ensure the proper functioning of a PA (E_2).

Perception of number of enforcement employees	Score
The number of enforcement employees is *way too low*	0.0
The number of enforcement employees is *slightly too low*	0.3
The number of enforcement employees is *adequate*	0.6
The number of enforcement employees is *slightly too high*	0.5
The number of enforcement employees is *way more than needed*	0.4

An enforcement employee is considered to be one full time equivalent (FTE). The optimum number of enforcement employees is based on studies of African PAs, where a ranger density of one ranger per 26–50 km^2 appears to be adequate to control poaching activities (Vreugdenhil, 2003; Lindsey et al., 2011; Henson et al., 2016). This ranger density was set as the optimum and a deviation from this density lowers the score. A too high ranger density is not ideal as this means that financial resources are spent on enforcement employees that do not enhance PA protection.

The Enforcement Employees sub-index, I_e, is calculated as follows:

$$I_e = E_1 + E_2$$

where E_1 represents the average amount of square kilometres to be patrolled by one enforcement employee, and E_2 represents the PA-managers' perception of the number of employees. See Table 4 and 5 for E_1 and E_2 respectively.

2.1.3. Controlled Visitor Access

Human presence is not by default detrimental for PAs. When managers can control visitor's behaviour, an effective balance between nature and humans can exists from which PAs can benefit (Marion & Reid, 2007; Parolo et al., 2009). The Controlled Visitor Access sub-index consists of three aspects: entrance and exit of the PA (Table 6), presence of pathways and/or shipping lanes (Table 7), and percentage of clearly indicated pathways or shipping lanes (Table 8). The score for this sub-index is the sum of these three aspects.

A PA that is fully fenced with only a limited number of entrances provides a high degree of control over visitors, but such a hard boundary significantly lowers connectivity between natural areas. Therefore, the highest score of 0.50 is assigned to a PA that is not fully enclosed with a fence, but where visitors are concentrated by using designated entrances to the PA (Table 6).

The presence of pathways and/or shipping lanes increases the control of visitors and results in a score of 0.25, no pathways/shipping lanes results in a score of 0.00 (Table 7).

When pathways are present visitors are more likely to use them when they are part of a well-managed route that is clearly indicated with directional signs to preferred destinations (Manning, 2014; Svobodova et al., 2019). Therefore, the higher the percentage of pathways that are part of a route, the more likely that visitors will use them. This leads to higher control of visitors potentially lowering their impact. More indicated routes lead to a higher score (Table 8).

The Controlled Visitor Access sub-index, I_{cva}, is a sum of the individual scores of the three abovementioned aspects:

$$I_{cva} = V_1 + V_2 + V_3$$

2.1.4. Funding

Funding has a major influence on the management of a PA, and thus the degree of nature protection. The funding sub-index consists of two parts, one part is based on the actual amount of funding the PA receives, the second part is based on the perception of the manager regarding this funding.

The score assigned to the first part, F_1, is based on the amount of funding the PA receives. Hereby we correct for both the total surface area of the PA and the Gross National Product of the country in which the PA is located. The value of the following ratio determines the score for this first part:

$F_1 = \frac{\left(\frac{F_{PA}}{A_{PA}}\right)}{GNI}$ where F_{PA} is the average funding the PA receives on a yearly basis, A_{PA} is the total surface area of the PA (in km^2) and GNI is the Gross National Income per capita of the country in which the PA is located.

A maximum score for F_1 is obtained when this ratio equals 0.50, because we assumed that a funding per 1 km^2 that equals half of the average income of a person in the country is sufficient to sustain effective management of a PA. This assumption is based on data from Bovarnick et al. (2010) for the financial sustainability of American PAs.

As all sub-indices have a range from 0 to 1, an upper limit is created by assuming that a F_1 value of 0.50 is sufficiently high (if $F_1 > 0.50$, then $F_1 = 0.50$). Using the data from Bovarnick et al. (2010) on the financial sustainability of American PAs the average Funding index would be 0.044 with a maximum of 0.16, yet they state that double the amount

Table 6
Scores of the different ways to access a PA (V_1).

Access to the PA	Score (V_1)
The PA is fully fenced (or de facto protected due to geographical circumstances) and can only be accessed via a limited number of entrances	0.25
The PA has no fence and can be accessed anywhere along the border	0.00
The PA has no fence, but concentrates visitors by using designated entrances (e.g. parking lots, public transport connections, visitor centres, harbours)	0.50

Table 7
Scores of presence of pathways/shipping lanes (V_2).

Presence of pathways/shipping lanes	Score (V_2)
Pathways/shipping lanes are not present	0.00
Pathways/shipping lanes are present	0.25

Table 8
Scores of indicated signposted pathways/shipping lanes as percentage of total length of paths/lanes in PA (V_3).

Percentage of indicated or signposted pathways/shipping lanes	Score (V3)
0%	0.00
1–20%	0.05
21–40%	0.10
41–60%	0.15
61–80%	0.20
81–100%	0.25

would be more optimal. Therefore, we assumed a Funding index of 0.3 to be optimal, whereas 0.5 (or higher) would be more than sufficient for an effective management of a PA.

The score assigned to the second part of the Funding index, F_2, is determined by the perception of the PA management of funding (Table 9).

The Funding sub-index, I_f, is then the sum of the two parts:

$$I_f = F_1 + F_2$$

2.1.5. *Corruption Regulations*

The Corruption Regulations sub-index is made up by the Corruption Perception Index of the country in which the PA is located as calculated by Transparency International on a yearly basis, divided into 10 score-classes (Table 10).

The perception of the manager whether corruption is actually higher or lower in the PA then for the country, can change the final score. If the corruption is perceived to be much higher than, slightly higher than, equal, slightly lower than or much lower than for the country, the score-class changes by –0.2, –0.1, 0, +0.1 or +0.2 respectively (Table 11). In case the score becomes lower than 0 or higher than 1, the values 0 and 1 are used, respectively.

2.1.6. *Biodiversity*

Biodiversity strongly depends on the type of ecosystem, e.g. tropical rainforests have much higher species densities than deserts. Therefore, the Biodiversity sub-index is not designed to quantify and evaluate only species diversity, but rather to assess the effort put in by the PA management to monitor and safeguard the (natural or original) biodiversity in their PA. The Biodiversity index I_b is calculated as follows:

$$I_b = \frac{B_1 + (B_2 * k) + B_3 + B_4}{4}$$ where

B_x depends on the answers to the following questions:

B_1 Is the biodiversity measured in one way or another? (1 if yes, 0 if no)

B_2 Are historical reference data available? (1 if yes, 0 if no)

B_3 Are there non-native species present? (1 if yes, 0 if no)

B_4 What is the impact of non-native species? (1 if positive, 0 if negative, 0.5 if neutral)

The B_2 term is multiplied by k (0–1), which is the average fraction of how many species are present today compared to about 50 years ago (in case the current species diversity is higher than 50 years ago, then *k* equals 1).

Table 9
Scores of the perception of funding by the PA manager (F_2).

Perception of manager on amount of funding	Score (F_2)
Absolutely insufficient, critical lack of funding	0.1
Partly insufficient, the PA management can go on but there is still a big lack of funding	0.2
Sufficient, all (required) management actions can be executed	0.3
More than sufficient, enough funding for proper management and some additional actions	0.4
Superfluous, more than enough funding for management and many additional actions	0.5

Table 10
The Corruption Perception Index (CPI) divided into 10 score-classes.

CPI	Score
1–10	0.1
11–20	0.2
21–30	0.3
31–40	0.4
41–50	0.5
51–60	0.6
61–70	0.7
71–80	0.8
81–90	0.9
91–100	1.0

Table 11
Scores of the perception on corruption by the PA manager.

Perception of PA management on corruption in their PA	Score change
Corruption in the PA is much higher than in the country	−0.2
Corruption in the PA is slightly higher than in the country	−0.1
Corruption in the PA is equal to that in the country	0.0
Corruption in the PA is slightly lower than in the country	+0.1
Corruption in the PA is much lower than in the country	+0.2

2.1.7. *Management objectives*

A list of twelve management objectives (Table 12) is used to derive the score for the Management Objectives sub-index. For every management objective present in the management plan 1 point can be scored. If there is no management plan, but the day-to-day management of the PA does incorporate one of the management objectives, 0.5 points can be scored for each objective. The final score is the addition of all scores divided by twelve.

2.1.8. *Edge effect*

The boundary of a PA forms the contact zone between protected and unprotected area. The longer the contact zone, the higher the chance that the PA is negatively influenced by the adjacent unprotected area (Woodroffe & Ginsberg, 1998; Ries & Sisk, 2004, Balme et al., 2010). Moreover, the longer the PA border, the more effort must be put in

Table 12
List of management objectives.

Management objective
Protection of endangered species
Protection of a nationally significant landscape
Protection of ecosystem services
Protection of cultural sites
Protection of natural resources for sustainable use
Providing food or other products for the markets/Provide benefits to the local and national economy
Maintaining natural processes
Preserve significant natural features
Safeguard the genetic diversity
Provide recreation and tourism services
Provide education, research and environmental monitoring
Provide homes to human communities with traditional cultures and knowledge of nature

controlling (illegal) in- and outflows. Therefore, the desirable situation is a PA with a PA border length as short as possible. The score of the Edge Effect sub-index is the ratio between the actual PA perimeter and the ideal perimeter (as if the PA had a circular shape):

$I_{ee} = \frac{P_{ideal}}{P_{PA}} = \frac{2\pi\sqrt{\frac{A_{PA}}{\pi}}}{P_{PA}}$ where A_{PA} is the total surface area of the PA (in m^2) and P_{PA} is the perimeter of the PA (in m).

2.1.9. Naturalness

Most commonly the rationale behind a PA is to maximise natural aspects and to minimise human impact and anthropogenic structures. Therefore, the Naturalness sub-index of a PA is the fraction of the PA surface area that is occupied with natural structures. This natural area occupation is calculated by subtracting the surface area of all anthropogenic structures, e.g. settlements, agricultural land or aquaculture and traffic roads, from the total PA surface area.

The Naturalness sub-index, I_n, represents the surface area of non-anthropogenic structures as a fraction of the total PA area:

$I_n = \frac{A_{PA} - A_{antrop}}{A_{PA}}$ where A_{PA} is the total surface area of the PA (in m^2) and A_{antrop} is the total surface area of the anthropogenic structures inside the border of the PA (in m^2).

When considering roads in a PA, not only the road surface itself is considered to be man-made, but also the shoulders. Dirt roads are excluded from the calculation of anthropogenic structures, as being difficult to recognise with GIS in forested areas and considered to be much less disturbing to nature than paved roads.

The surface area of an anthropogenic structure was calculated in ArcMAP version 10.8 (ESRI, 2020) using shapefiles supplied by the PA managers or by manually drawing polygons based on satellite images of the PA. A buffer zone is added on both sides of roads, to account for the shoulders (maintenance of vegetation, signs or milestones, streetlights, etc.). The width of this buffer zone depends on the type of road. Table 13 shows the three types of roads distinguished by PLI.

For the calculation of the anthropogenic surface area related to roads, all primary roads are regarded as 4 lane roads, assuming a lane width of 4 m, the anthropogenic surface area covered by primary roads equals the total length of the primary roads (in m) multiplied by 46 m. Same for secondary roads, from which the length is multiplied with 28 m and for tertiary roads the length is multiplied by 14 m (Fig. 1).

2.1.10. Light pollution

Artificial lights in the night originating from human settlements, can disrupt the natural behaviour of plants and animals and is therefore regarded as a negative impact on the degree of protection in a PA (Aschoff, 1960; Longcore & Rich, 2004, Chepesiuk, 2009, Sanders et al., 2021, Ditmer et al., 2020). The Light Pollution sub-index assesses the artificial light intensities that occur in a PA, using the Zenith sky brightness scale. The online light pollution map as produced by Falchi et al. (2016) has been used. For ease of calculation their scale has been divided into three categories (Table 14). For the PA the fraction of the total surface area falling into each category is derived from GIS, by manually drawing polygons based on the light pollution map of the PA in ArcMAP, multiplied with the associated score for each category. The Light Pollution sub-index equals the sum of aforementioned three products of surface fraction and scores.

The Light Pollution sub-index is calculated as follows:

$I_{lp} = \left(\frac{A_1}{A_{PA}}*1.0\right) + \left(\frac{A_2}{A_{PA}}*0.5\right) + \left(\frac{A_3}{A_{PA}}*0\right)$ where A_{PA} is the total surface area of the PA (in m^2) and A_1, A_2 and A_3 are respectively the total surface areas of the PA (in m^2) that fall in the low, medium and high light categories (Table 14).

2.1.11. Fragmentation

Fragmentation lowers the connectivity in a PA (Bruschi et al., 2015), and has a negative impact on gene flow between populations (Corlatti et al., 2009). The Fragmentation index assesses the degree of fragmentation (i.e. number of fragments) caused by primary and secondary roads (for definitions see Table 13). Tertiary roads are not considered, because those are narrow enough and with a sufficiently low enough intensity, that they can safely be crossed by animals.

The Fragmentation sub-index is based on (1) the number of fragments, since a highly fragmented PA is more difficult to manage than one with less fragments, and (2) the surface area of the fragments. A PA with one large fragment and a few smaller fragments provides a larger surface area of undisturbed habitat compared to a PA with the same number of fragments, but with equally sized, smaller fragments.

The Fragmentation sub-index is calculated as follows:

$I_{frag} = \frac{0.5}{f} + 0.5*\frac{A_{largestfrag}}{A_{PA}}$ where f is the number of fragments, $A_{largestfrag}$ is the surface area of the largest fragment in the PA (in m^2) and A_{PA} is the total surface area of the PA (in m^2).

2.1.12. Expandability

Generally, the degree of protection increases towards the centre of a PA, because the outer zone of a PA is closer to unprotected areas and subsequently experiences higher distortion from humans (Woodroffe & Ginsberg, 1998; Ries & Sisk, 2004; Balme et al., 2010). Accordingly, a PA manager may always explore possibilities to expand the PA.

The Expandability sub-index is the potential of a PA to expand its borders. To standardise the possibility of expansion we measure the possibility of expansion by creating an expansion band, which is 20 % of the radius of a circle that has the same surface area as the PA. Parts of the expansion band that are covered by anthropogenic structures are summed and subtracted from the total surface area of the expansion band. This was done in ArcMAP (ESRI, 2020). The area of this expansion band that falls under different management authorities or are beyond national jurisdiction (for example neighbouring countries) are subtracted from the total area of the expansion band, because they are often included in neighbouring PAs. The Expandability Index is the ratio of the surface area that remains for expansion relative to the total surface of the expansion band. The desirable situation (giving a maximum score of 1) is a band that is entirely free for PA expansion. The Expandability sub-index, I_{exp}, is calculated as follows:

$I_{exp} = \frac{A_{expband} - A_{antropogenicinexp}}{A_{expband}}$ where $A_{expband}$ is the total surface area of the expansion band (in m^2) and $A_{antropogenicinexp}$ is the total surface area of the anthropogenic structures that fall within the expansion band (in m^2).

2.2. Calculation of the total protection level index

For calculating the total Protection Level Index all sub – indices area summed and divided by twelve:

$PLI = \frac{I_i + I_e + I_{cva} + I_f + I_{cr} + I_b + I_{mo} + I_{ee} + I_n + I_{lp} + I_{frag} + I_{exp}}{12}$

For explanation of the abbreviations, see Table 1.

2.3. Graphical representation

To be able to easily compare PLI scores of different PA, or for the same PA in different years, a graphical representation similar to an AMOEBA diagram is used. The colours in the diagram represent the

Table 13
Division of paved roads into three categories.

Road type	Total road width	Number of lanes	Degree of through traffic	Width buffer zone
Primary roads	>20 m	>2 lanes	High (high ways)	15 m
Secondary roads	10–20 m	2 lanes	Medium	10 m
Tertiary roads	<10 m	1 lane	Low (local roads)	5 m

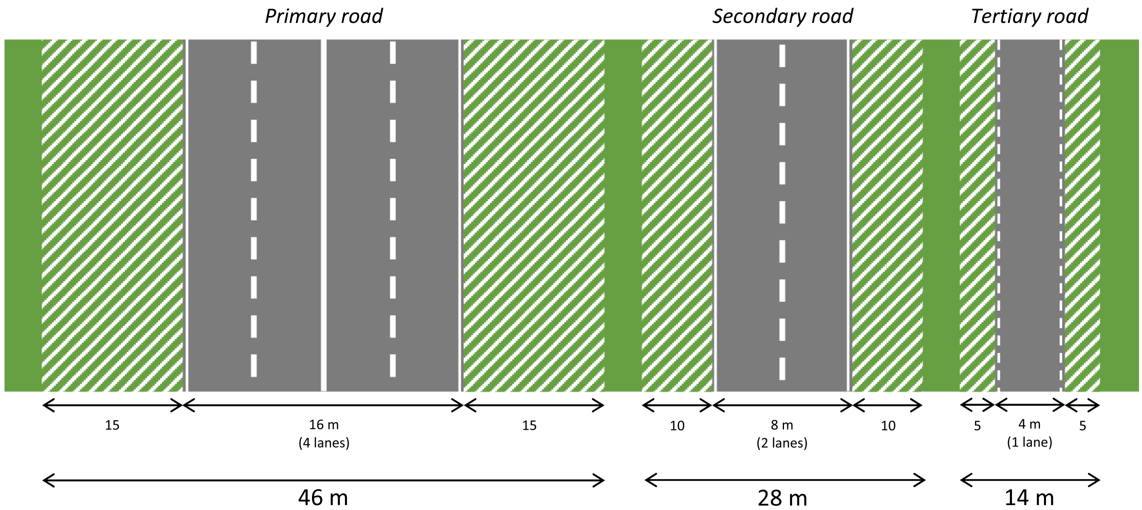

Fig. 1. Widths of primary, secondary and tertiary roads together with the widths of their corresponding buffer zones.

Table 14
The three categories of light pollution.

Category	Zenith sky brightness scale (magnitude/arcsecond^2)	Score
Low	22.0 to 21.7	1.0
Medium	21.7 to 20.6	0.5
High	20.6 to 17.5	0

score of the PA for a certain index. Red is a score between 0 and 0.2, orange is a score between 0.2 and 0.4, yellow is a score between 0.4 and 0.6, green is a score between 0.6 and 0.8, and blue is a score between 0.8 and 1.0. Graphs have been plotted in R (2019), using the tidyverse library (Wickham et al., 2019). The R script used can be found in Appendix 2.

2.4. Data collection at case-study areas

To test the applicability and practicality of measuring PLI factors in PAs, the PA managers of a number of case-study areas were visited and interviewed (Table 15, Fig. 2).

At least 2 interviewers were present during the face-to-face interviews with PA managers, and they raised and explained the questions following a standard interview-protocol (Appendix 1). One interviewer was leading the discussion and the second interviewer noted the answers.

The answers were used for the above-mentioned calculations (2.1, 2.2.) in order to compose the PLI.

Table 15
Protected Areas that participated in the development of PLI.

Official name	Country	Year of foundation	IUCN Category	Realm
Lake Prespa Monument of Nature	North-Macedonia	1995	III	Lake
Pieniny National Park	Slovak Republic	1967	II	Mountainous/ forest
Danube Delta Biosphere Reserve	Romania	1991	II	River delta
Island Network of Protected Areas – La Palma	Spain	1994	I-VI	Island
Curonian Spit National Park	Lithuania	1991	II	Beach/dunes/ forest
Bavarian Forest National Park	Germany	1970	II	Mountainous/ forest
Kalkalpen National Park	Austria	1997	II	Mountainous/ forest

3. Results: case studies

A total of 7 European PAs (Table 15 and Fig. 2) participated in the development of the PLI methodology. The wide range of terrestrial and aquatic environments and different designations that are covered by these 7 PAs enabled the development of the universal character of PLI. A detailed description of the PAs, and GIS maps can be found in Appendix 3. Scores of the different indices and final PLI scores are provided in Fig. 3 and Table 16.

For some of the PLI sub-indices, such as the Illegal Activities index, the Biodiversity index, the Naturalness index, the Light Pollution index and the Expandability index the PAs show very similar scores (Table 16). Whereas the scores for the other PLI sub-indices show a great variability between the 7 PAs. For example, the scores for the Enforcement Employees index range from 0.00 for the Danube Delta to 0.80 for the Bavarian Forest and for the Fragmentation index, scores range from 0.18 for La Palma to 1.00 for the Danube Delta.

Also the data sources give additional variation to the results. The highest sub-indices derived from interviews derived were for Bavarian Forest and Kalkalpen National Park, and the lowest scores were for Lake Prespa Monument of Nature and Pieniny National Park. Whereas the highest sub-indices derived with GIS were obtained for Pieniny National Park and Danube Delta Biosphere Reserve. (Table 16). Despite the strong variation in the scores of the sub-indices, all 7 PAs have a more moderately differentiating final PLI score. The lowest final PLI score is 0.56 for the Island Network of Protected Areas in La Palma and the highest final PLI score is 0.80 for the Kalkalpen National Park.

A potential relationship between all the sub-indices was determined and tested for significance. Statistical tests were performed on all possible relationships and the significance of the correlation coefficient was calculated adopting the Dunn–Šidák correction for multiple comparisons. Given 12 indices a total of 66 linear relationships were tested with a 'population-wise' alpha level of 0.10, whereby each individual null hypothesis is rejected that has a p-value higher than 0.002. Given 7 PAs, thus with five (5) degrees of freedom, the corresponding correlation coefficient needed to be higher than 0.93 (in a few cases with less pairs of Biodiversity indices the degrees of freedom were two (2) and the correlation coefficient had to be higher than 0.998). Even when tested under a significance level of only $\alpha = 0.10$, yet with a Dunn–Šidák correction to counteract problems with multiple comparisons, there were among the 66 comparisons, not any significant (positive or

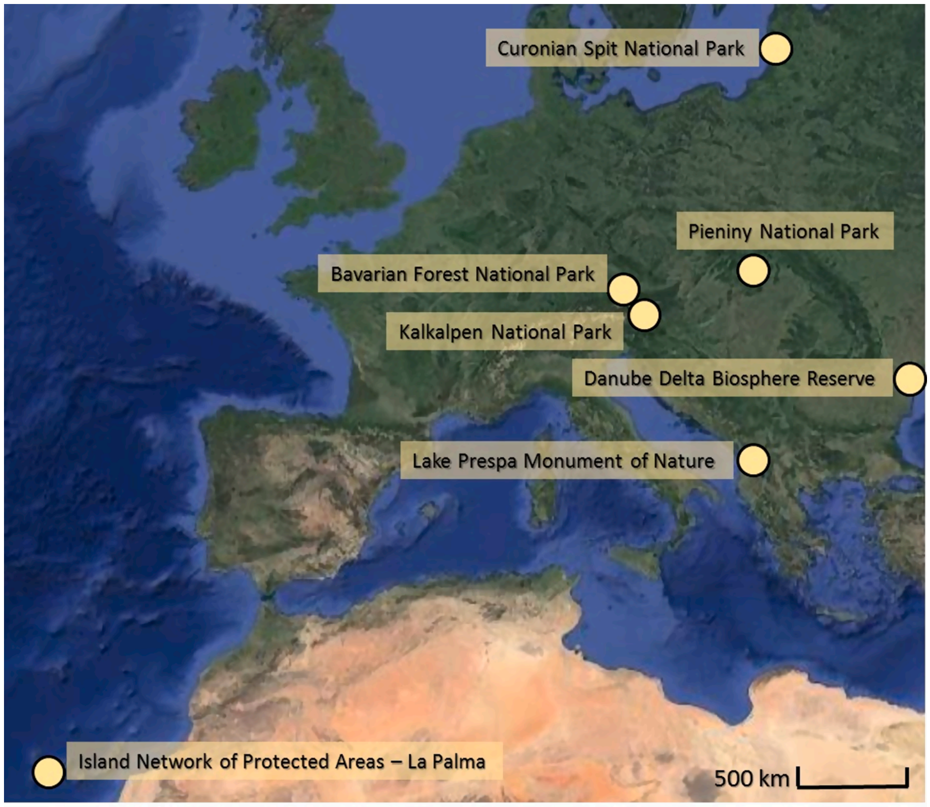

Fig. 2. Map of the Protected Areas that participated in the development of PLI (based on Google Maps).

negative) relations to be found.

4. Discussion

Significant efforts have been made by different countries to develop and apply methodologies to assess the PA management effectiveness (Blanco and Gabaldon, 1992; Courrau, 1999; Dudley et al., 1999; Hockings et al., 2000; Cifuentes et al., 2000; Ervin, 2003a; Stolton et al., 2003; Blom et al., 2004; BirdLife International, 2006; Leroux et al., 2010; Mc Arthur et al., 2010). Most of these papers present outlines and reviews on the development and implementation of methods and metrics to be used, often together with a few case-studies. The methods and metrics concern mainly managerial related factors, in several cases with contextual environmental or socio-economic factors that may pose a threat on the management of the areas. However, the majority of methods are not globally applicable, often do not focus on the effects of protection regulations in the field, and comparisons between PAs may be complicated because of different methodological approaches (Hockings & Phillips, 1999; Pomeroy et al., 2004; Stoll-Kleemann, 2010).

An overview of the basic methods and metrics used in many of the PA management effectiveness approaches can be found in the reviews by Pomeroy et al (2004) and Leverington et al. (2008, 2010). Though focussing on marine PAs, Pomeroy et al. (2004) present in their guidebook an extensive overview of possible environmental, socio-economic, and managerial metrics to evaluate PA management effectiveness. For a pity, they do not present a concise index, and so leave the end-user still to make own choices, whereby consequently not any PA will be comparable to another because of those individual choices.

In contrast to the multidisciplinary approach of Pomeroy et al (2004), most recent manuscripts on PA protection and management effectiveness focus on a restricted disciplinary approach, and refrain from using a combination of environmental, socio-economic as well as managerial aspects.

Such restricted sets of metrics focus often on environmental or ecological aspects, such as, for example, the protection of selected species, specific habitats, or ecosystems (Mikoláš et al., 2017; Brown et al., 2019; Riggio et al., 2019; Cazalis et al., 2020; Terraube et al., 2020), trends and spatial patterns of biodiversity (Hoffmann et al., 2017; Brown et al., 2019; Riggio et al., 2019), or habitat status (Friedrichs et al., 2018). Other metrics relate more to socio-economic aspects such as the scale and extent of threats as e.g. deforestation (Eklund et al., 2019; Negret et al., 2020; Wolf et al., 2021), obtaining positive social impact or local support (Bennett et al., 2019; Jones et al., 2020), and behavioural changes of people (Cazalis & Prévot, 2019). Or key parameters are managerial issues such as management inputs or good governance and their impact on a PA (Eklund et al., 2019; Armitage et al., 2020).

Moreover, these recent focused studies lean in most cases strongly on the analysis of existing databases and do not include on-site field research nor involve the view of PA practitioners. An exception being the studies focussing on socio-economic aspects by Bennett et al (2019) and Jones et al (2020), who include the views of fishermen and inhabitants, respectively, in and around the PAs.

At present, several dozen methodologies (over ninety according Stoll-Kleemann, 2010) are used at the national or global level to evaluate the effectiveness of management, of which the two most widely used management effectiveness methodologies are RAPPAM and METT (Stoll-Kleemann, 2010; Worboys et al., 2015; Coad et al 2015). Both these methods are mainly based on the assessment of management performance, for which the basic information is usually assembled through scorecards and workshops in one to three days, though a follow-up by assessment-agency workers may be needed in case outcomes of factors have to be evaluated (Hockings et al 2000; Coad et al. 2015). Assessments including also environmental and socio-economic information, such as the Enhancing Our Heritage (EoH) methodology of UNESCO, require considerably more resources and may take up to a few months (Stoll-Kleemann, 2010; Coad et al 2015).

The Rapid Assessment and Prioritisation of Protected Area Management methodology (RAPPAM) is by far the most commonly applied

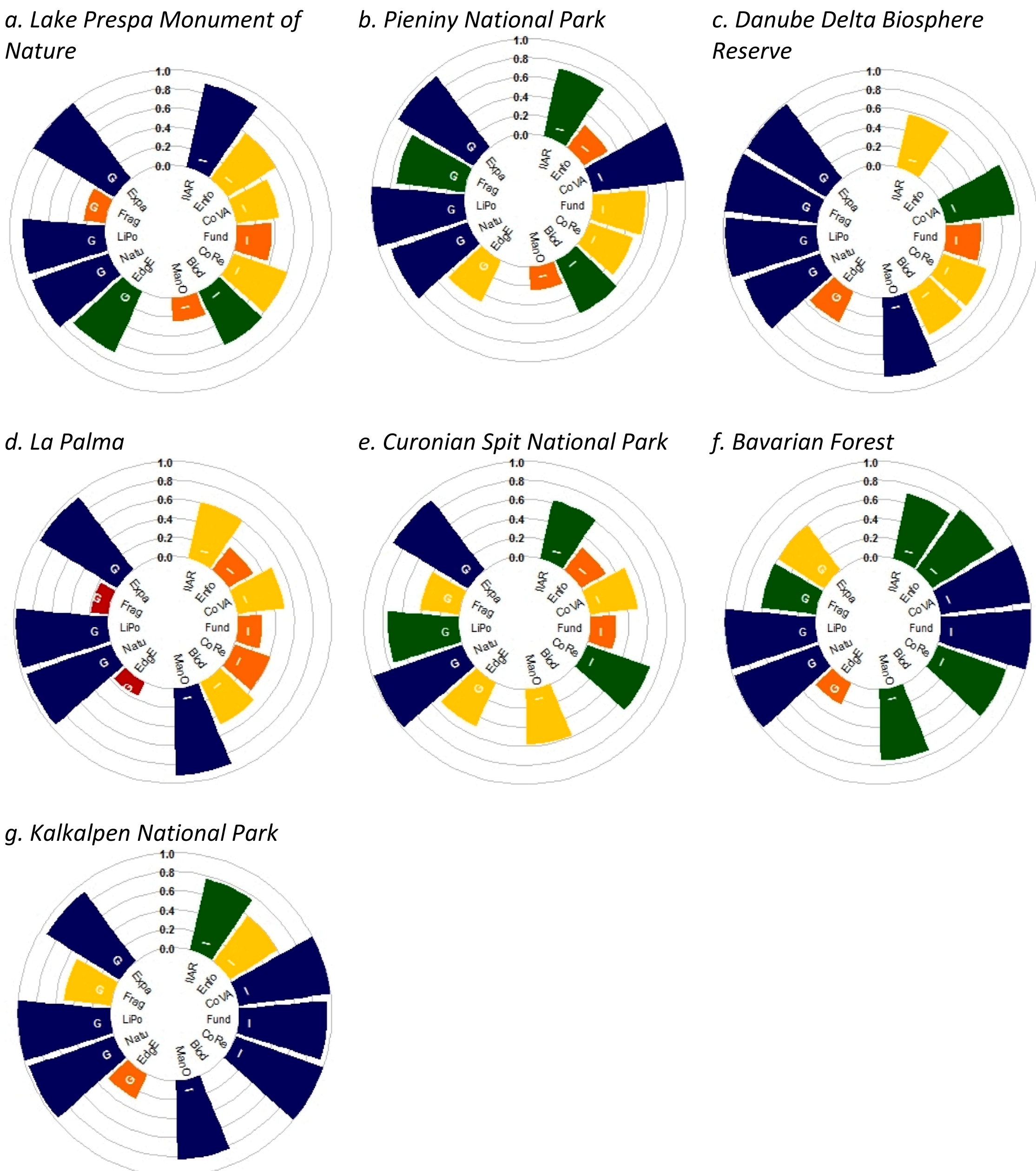

Fig. 3. PLI scores for the 7 PAs. A score of 0 reflects a poor situation, 1 a desirable situation; "I" indicates a variable derived from the PLI Interview, "G" indicates a GIS derived variable. A red bar corresponds to a value between 0.0 and 0.2, orange between 0.2 and 0.4, yellow between 0.4 and 0.6, green between 0.6 and 0.98, and blue between 0.8 and 1.0. For abbreviations of the PAs see Table 1. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

PA management effectiveness methodology (Ervin, 2003a; Stoll-Kleemann, 2010; Worboys et al., 2015; Coad et al 2015). Like PLI, the collection of data occurs via a questionnaire. The RAPPAM questionnaire is filled out during one or more participatory workshops with PA managers, administrators and stakeholders (Ervin, 2003b). RAPPAM encourages the incorporation of preliminary assessments and existing data such as aerial photos, satellite imagery, biodiversity reviews, anthropological and sociological studies, threat analyses and/or legal and policy reviews (Ervin, 2003b). However, this is a rather time-consuming effort, and moreover, the assessment of PAs using RAPPAM may likely be biased due to differences in the availability of such preliminary data.

PLI does not require lengthy workshops and is not discriminatory towards the presence or absence of preliminary assessments and/or existing datasets. The PLI questionnaire takes up a maximum of 2 hours and the spatial analysis in GIS takes about 4–6 hours depending on the quality and resolution of the shapefiles. This makes PLI a relatively fast and cost-efficient method that does not require lots of time and resources from PA management, and can thus easily be repeated every year to assess whether their management (eventually focused on specific sub-indices) has been efficient and subsequently the protection level of the PA has been enhanced.

The Management Effectiveness Tracking Tool (METT) developed by the World Bank/WWF Alliance is the second most used PA effectiveness measure at present. The METT questionnaire consists of multiple-choice questions for which the answers correspond to scores ranging from 0 to 3. Like PLI, the METT questionnaire contains questions regarding the perception of the PA managers on aspects such as the adequacy of the number of staff and the amount of funding. In the METT methodology all questions are equally weighted and managers are allowed to exclude

Table 16
PLI scores of the different PAs.

	Lake Prespa	Pieniny	Danube Delta	La Palma	Curonian Spit	Bavarian Forest	Kalkalpen
Illegal Activities	0,90	0,73	0,57	0,60	0,62	0,70	0,76
Enforcement Employees	0,60	0,30	0,00	0,30	0,30	0,80	0,60
Controlled Visitor Access	0,45	1,00	0,75	0,50	0,50	1,00	1,00
Funding	0,37	0,57	0,37	0,26	0,27	1,00	0,95
Corruption Regulations	0,60	0,50	0,50	0,40	0,70	0,80	1,00
Biodiversity	0,63	0,62	0,50	0,49	–	–	–
Management Objectives	0,25	0,25	0,83	0,92	0,58	0,75	0,83
Edge Effects	0,70	0,49	0,36	0,16	0,51	0,26	0,28
Naturalness	0,85	0,88	0,86	0,96	0,98	0,99	0,97
Light Pollution	0,86	1,00	0,98	0,98	0,74	1,00	1,00
Fragmentation	0,23	0,74	1,00	0,18	0,41	0,61	0,51
Expandability	1,00	0,95	0,99	0,96	0,92	0,59	0,92
Average PLI score	*0,62*	*0,67*	*0,64*	*0,56*	*0,59*	*0,77*	*0,80*

questions of which they believe are irrelevant for their PA. The final METT score is calculated as a percentage of the scores from those questions that were relevant to a particular PA. The developers of METT noted that this approach leads to limitations in terms of allowing comparisons between different PAs (Stolton et al., 2003).

While PLI mimics the METT-approach of using equal weights for different factors, PLI does not allow for the exclusion of any of the given factors by the PA management. In this way, each PA is assessed on the exact same set of sub-indices, making PLI more globally applicable and comparable between various PAs than METT.

Therefore, in this study we have developed a new index, the Protection Level Index (PLI), which evaluates the actual level of protection in the PA by assessing managerial, socio-economic as well as environmental factors, allows for an easy comparison between PAs, and the assessment can be carried out together with the PA management within 1 day.

One of the innovative aspects of PLI is that it has a different way of dealing with the issue of defining standard optimal conditions. In PLI the acceptable range of variation for some of the indices are not predefined but instead determined by the perception of the PA manager. In this way, the PA manager can place the conditions in context and has the possibility to assess whether these conditions are optimal. The reason for this approach is that each PA is different and the optimal conditions may vary from PA to PA. Due to its nature, PLI can be used to estimate the level of protection, and keep track of temporal changes in protection level.

The lack of any relation between the sub-indices emphasises that none of the PLI sub-indices can be explained by the scores of other sub-indices. This indicates that each individual sub-index forms an equal-weighted part of PLI without being influenced by any other sub-index. This underlines the need that the final PLI score should always be accompanied by the individual scores for the sub-indices to aid the PA management in deciding on the most efficient procedures to increase the quality and protection of their PA.

Finally, the sub-indices of PLI were developed in such a way that they are applicable to terrestrial and aquatic PAs. To this end, we have identified aquatic equivalents of terrestrial components in PLI, e.g. aquaculture for agriculture and shipping lanes for traffic roads. Our analyses show that PLI turns out to be a rather neutral unbiased measure with regard to the evaluation of PAs from various terrestrial and aquatic realms. Nevertheless, we also recognise that some PLI sub-indices may not be as suiTable for especially full marine PAs as they are for other aquatic (e.g. coastal) and for terrestrial PAs, and future efforts are recommended in order to improve the applicability of PLI to such very specific PAs.

Nevertheless, in comparison to most other above mentioned PA management effectiveness methods, PLI combines a multi-disciplinary character of its indicators, with a relatively fast, and thereby cost-effective, procedure, established in cooperation with the PA management that can indicate the present and in-situ condition of the PA.

5. Conclusion

The Protection Level Index (PLI) is a new Protected Area (PA) effectiveness measure that allows for a relatively simple assessment of the degree of protection in any type of PA in the world. It could complement the IUCN categorising system, in that the IUCN Category assesses the management strategy (on paper) and PLI assesses the actual effects of this management strategy in the field. This makes PLI capable of exposing so called “paper parks”. The final PLI score of a PA ranges from 0 (undesirable) to 1 (desirable) and is the average score of 12 equally weighted indices. These indices are a selection of globally recognised indicators of PA management effectiveness.

PLI is faster than RAPPAM (WWF) and more widely applicable than METT (World Bank/WWF Alliance). It also introduces a new way of incorporating the perception of the PA managers in the scoring and thereby delivers a work around for the issue of pre-defining universal optimal conditions, which is not always possible, or for which costly research is needed to construct baselines. Concluding, PLI is a useful tool for PA managers as it offers a practical, and cost-effective assessment of the effects of the current management strategy for any type of PA worldwide. Due to its uncomplicated, non-time-consuming nature, PLI could be carried out on a yearly basis to assess the status of a PA.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.

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